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GUIDELINES FOR ENFORCEMENT AND SURVEILLANCE OF SUPPLEMENTARY CONTROL SYSTEMS.

VOLUMES I AND II

PACIFIC ENVIRONMENTAL SERVICES, INCORPORATED

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GUIDELINES FOR ENFORCEMENT AND SURVEILLANCE OF SUPPLEMENTARY CONTROL SYSTEMS

Volumes I & II

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16. ABSTRACT

Guidelines for the enforcement and surveillance of Supplementary Control Systems (SCS) are presented in two Volumes. 35 References. For Volume I these include:

1. Description of SCS elements and discussion of SCS violations
2. Types of inspections and review procedures used for surveillance and enforcement
3. Inspection and calibration procedures (together with sample checklists and forms) for ambient and emission monitors and meteorological instruments.

Volume II contains detailed background information on inspection and calibration of SO_2 ambient and emission monitors and meteorological instruments.

This document is not a research report. It is designed for use by operating personnel.

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GUIDELINES FOR ENFORCEMENT AND SURVEILLANCE OF SUPPLEMENTARY CONTROL SYSTEMS

by

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September 1975

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The Enforcement Technical Guideline series of reports is issued by the Office of Enforcement, Environmental Protection Agency, to assist the Regional Offices in activities related to enforcement of implementation plans, new source emission standards, and hazardous emission standards to be developed under the Clean Air Act. Copies of Enforcement Technical Guideline reports are available - as supplies permit - from Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or may be obtained, for a nominal cost, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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FOREWORD

Pacific Environmental Services, Inc. is pleased to submit this report to the United States Environmental Protection Agency (EPA) in partial fulfillment of the requirements under Contract No. 68-02-1390 - "Preparation of Guideline for Enforcement and Surveillance of Supplementary Control Systems." Volume I of these guidelines provides guidance to control agencies in their surveillance and enforcement of proper conditions of operations of an SCS, including suggested forms for conducting the various inspections or reviews considered necessary. Volume II provides detailed background information on inspection and calibration of SO_2 ambient and emission monitors and meteorological instruments.

We wish to acknowledge the assistance of Mr. Geoffrey Grubbs, EPA Project Officer in the work associated with this project and in the preparation of these guidelines.

GUIDELINES FOR ENFORCEMENT AND SURVEILLANCE OF SUPPLEMENTARY CONTROL SYSTEMS

Volume I

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SECTION I
INTRODUCTION

1.1 BACKGROUND

The Environmental Protection Agency (EPA) has proposed amendments to 40 CFR Part 51 regulations (Ref. 1) which would allow selective use of supplementary control systems (SCS) in order to achieve and maintain National Ambient Air Quality Standards (NAAQS) for SO_2 in cases where permanent production curtailment, shutdown, or delays in attainment of the national standards are the only other alternatives.

While these proposed (Sept. 14, 1973) regulations have not been promulgated, the basic technical concept of SCS may be incorporated in individual regulations for the control of sulfur oxides. An example of such a regulation which applies to a specific non-ferrous smelter, may be found in Reference 2. Such regulations, promulgated in Part 52 of the Code of Federal Regulations, require the source to apply all available permanent controls and permit the use of SCS as a temporary means of attaining and maintaining NAAQS for SO_2 for these specific sources where plant closure or permanent production curtailment are the only other alternatives.

Procedures are contained in these Part 52 regulations which describe the steps to be employed by the source operator in making application for and in obtaining authority to use an SCS. Guidelines for Evaluating Supplementary Control Systems (Ref.3) describe the criteria and guidelines used for evaluating supplementary control systems and are referenced frequently in the surveillance and enforcement guidelines for SCS contained herein. Each request for approval to use SCS is evaluated either: (1) directly by EPA or (2) by the respective state agency subject to review and final approval by EPA. Once this final approval has been obtained, the source develops and tests a working SCS according to a prescribed compliance schedule. On the date specified in the compliance schedule, the owner or operator of the

SCS becomes responsible for attaining and maintaining the appropriate National Ambient Air Quality Standards.

A list of definitions and key terms employed in these guidelines is shown in Appendix A to Vol. I.

1.2 PURPOSE

These guidelines have been prepared for the use of the U.S. Environmental Protection Agency, State and local agencies to assist them in carrying out proper surveillance and enforcement of supplementary control systems (SCS) following the time that individual source owners first assume complete responsibility for meeting NAAQS for SO_2 within the area affected by the emissions from the source (called the designated liability area - DLA).

1.3 GENERAL DESCRIPTION OF A SUPPLEMENTARY CONTROL SYSTEM

Supplementary control systems (SCS) are systems by which stack emissions of sulfur dioxide (SO_2) are curtailed during periods when meteorological conditions conducive to ground-level concentrations in excess of the National Ambient Air Quality Standards (NAAQS) exist or are anticipated. According to established EPA regulations (e.g. Ref. 2), authority to operate an SCS will be received by the owner only after extensive efforts on his part which include:

- Installation of an emission monitoring system, air quality monitoring network, meteorological sensing network and development of a meteorological prediction program for his facility.
- Completion of a 120 day field study to demonstrate that the above mentioned monitoring networks, in conjunction with other available continuous emission controls, are in fact capable of attainment and maintenance of NAAQS for SO_2 in the designated liability area.
- Preparation and submission for approval of an operational manual which describes the location and type of all equipment used in the operation of the SCS, the functions and names of responsible personnel and the specific criteria by

which the source decides when to curtail emissions and by what amount.

Nearly every SCS system will employ two methods of controlling SO_2 stack emissions: open-loop and closed-loop control. The open-loop control method is the normal mode of SCS operation in which the curtailment decision is based primarily on the observation and/or prediction of atmospheric conditions over the next few hours. The closed-loop method can be considered an emergency or an override method of control and is exercised when actual ambient air quality monitor readings dictate immediate emission curtailment to prevent violations of NAAQS for SO_2.

SECTION 2

SURVEILLANCE AND ENFORCEMENT OF A SUPPLEMENTARY CONTROL SYSTEM

2.1 SCS VIOLATIONS

The primary task of the control agency is to monitor the source operator's SCS program for its effectiveness and to enforce the specific requirements of the regulations applicable to a source operating an approved SCS. Unless otherwise specified in the regulations the source operator is considered to be in violation of SCS regulations if at any time:

- Any National Ambient Air Quality Standard for SO_2 is exceeded after the owner or operator of the source assumes responsibility for the maintenance of such standard in the designated liability area. Any measured excess of a National Ambient Air Quality Standard for the specified averaging period (i.e. 3 hour, 24 hour or annual) at any monitor in the SCS network constitutes a violation. Repeated or consecutive excesses at the same monitor or non-simultaneous excesses at different monitors are multiple violations.

  The designated liability area (DLA) may occasionally change at a source and accurate information as to its delineation should be kept on file in the control agency office. The DLA can be redefined only with prior approval of the control agency.

- Failure to maintain suitable record of measurements and reports. Measurement records and reports must be in a useable form and readily retrievable. The types of information needed and acceptable formats for data storage should be approved by the control agency prior to the time that the source assumes responsibility for meeting NAAQS in the designated liability area.

- Failure to submit required monthly (or weekly) reports and summaries to the control agency. This could be extended to the failure of the SCS operator to telemeter data to the control agency if this were required.

- Failure to notify the control agency of any violation of NAAQS for SO_2 within 24 hours of the occurrence of such violation.

- Total SO_2 emission limits from the continuous emission control equipment available at the plant have been exceeded. The maximum authorized emission limit reflecting the application of available control technology will be contained in the SCS regulation for that source. It will be expressed either in PPM, lbs $SO_2/10^6$ BTU or lbs SO_2 per hour. The actual SO_2 emissions for the source are calculated using the test method and averaging time prescribed in the regulations for that source.

- Operations of the SCS are not conducted in accordance with procedures specified in the approved operational manual. These violations include but are not limited to:

    1. Failure of the SCS operator to take the appropriate curtailment action(s) when curtailment criteria specified in the operational manual are met. Note that the curtailment criteria and corresponding actions are described in the operational manual and that a failure of the SCS operator to curtail emissions at the times specified in the manual constitute a violations of the SCS regulations regardless of whether or not NAAQS have been exceeded.

       Some potential SCS applicants have indicated that curtailment actions will be taken in response to specific directions of a decision-making computer program, thus reducing the subjectivity involved with curtailment decisions. In all cases however, the control agency must determine if the correct decision was made and if so, whether it was properly executed. These determinations involve a comparison of meteorological data, air quality data and curtailment actions initiated by the source with the criteria for making such decisions as specified in the operational manual. Detailed guidance for evaluating these decisions is presented in Section 2.2 (Control Decisions).

2. Failure of the SCS operator to carry out the continuous system-upgrade procedures described in the operational manual. The success of these procedures is measured by the improvement in reliability of the SCS during the preceding year and by the improved ability of the source to avoid repeating ambient air quality violations under like sets of meteorological and atmospheric conditions. See Section 2.2 (Upgrade System) for further discussion and guidance.

3. Modification of the operational manual by the source operator without prior approval of the control agency. These modifications include changes of responsible personnel from those listed in the manual and changes in threshold values and corresponding curtailment actions.

2.2 ELEMENTS OF A SUPPLEMENTARY CONTROL SYSTEM

An understanding of the basic components of an SCS is essential to the surveillance and enforcement of an SCS at a source, particularly to the extent that these elements provide indications of noncompliance with SCS regulations. In this Section each SCS element is discussed separately and also as it relates to other elements or factors. The objective of this Section is to provide control agency personnel with a description of the numerous elements of an SCS and to provide detailed guidance in the analysis of the most important of these elements.

Control Decisions

The control decision element (the point at which a decision is made in response to changing atmospheric conditions) represents the heart of an SCS and an understanding of it is essential to any evalua-of an SCS. A detailed explanation of the various factors involved in the control decisions for a particular SCS are described in the operational manual for that source. These factors include:

- A description of conditions which, when met, will require a control decision
- Range of control decision alternates which may be expected for a given set of conditions (e.g. curtailment, shut down, process change, etc.).
- Who is authorized or expected to make such a decision (by name/title)

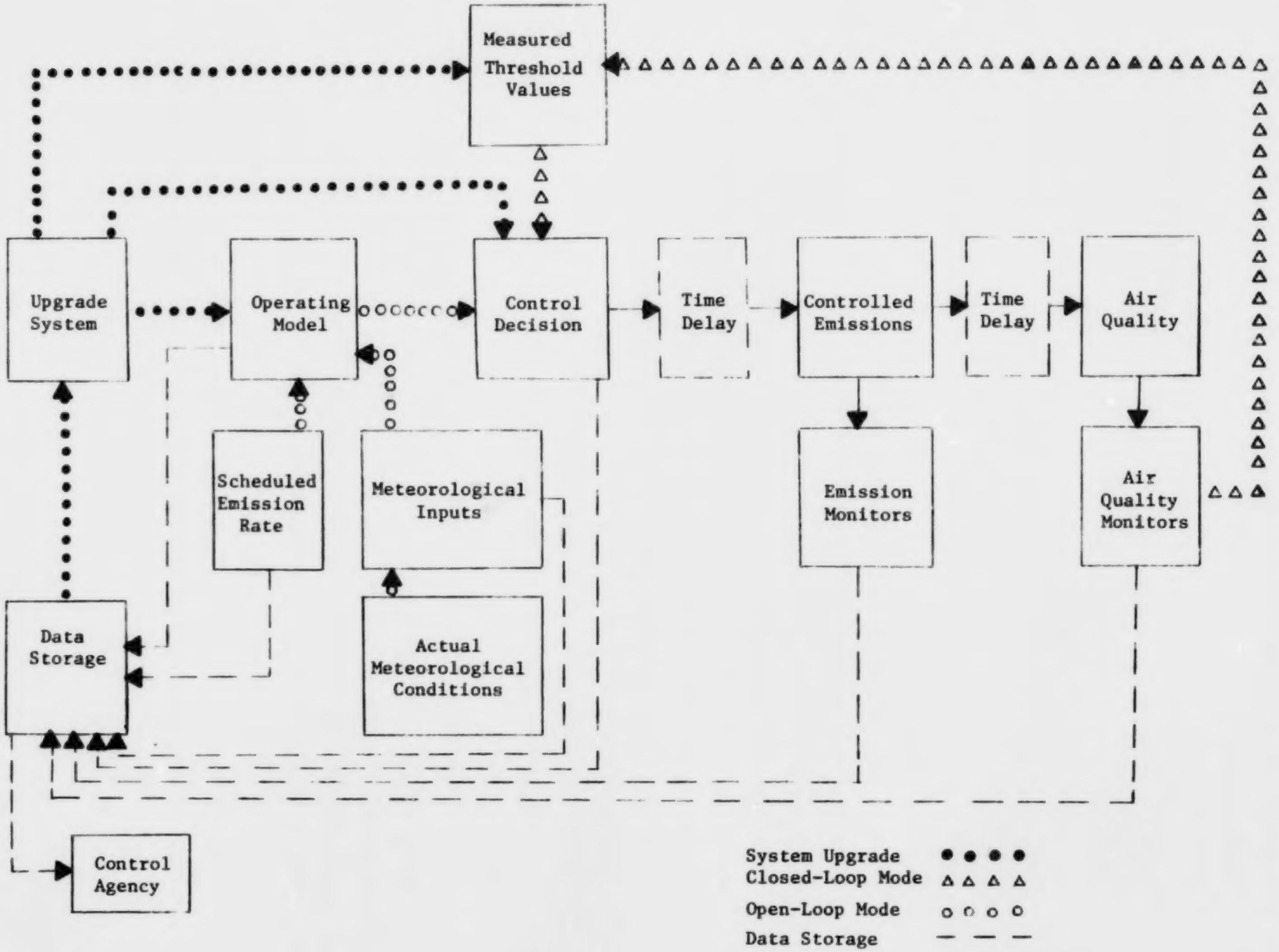
Any control decision is therefore capable of a detailed after-the-fact analysis to determine how well the control decision procedures specified in the operational manual were actually followed. Analysis of individual control decisions should be performed during a short inspection of the source, as described in Section 3.2 of this Volume. A more meaningful review is conducted during the Comprehensive inspection (described in Section 3.1) when the control decisions which have accumulated over a period of time are analyzed for any trends in either improved or decreased performance.

Instances of reported air quality violations will be a matter of record in the control agency files and a review of the circumstances surrounding these violations should be performed. In addition, source operator records should be examined as a cross check for instances when threshold values were recorded or when critical meteorological conditions occurred or were predicted to occur. A determination should then be made as to what control decision, if any, had been made and by whom. This decision should be compared to the control decision criteria specified in the operational manual. Corroborative evidence of the occurrence of threshhold values or critical meteorological conditions should be obtained from control agency ambient monitoring records and from independent weather stations covering the designated liability area.

The functional diagram shown in Figure 2-1 is useful in understanding the influence of other SCS elements upon the various control decisions under examination. The evaluation of this element should be conducted by the most experienced member of the inspection team, assisted by other members as necessary. It requires a broad knowledge of all SCS elements, together with an understanding of management principles. Since the procedures for implementing these control decisions will have been previously set forth in the operational manual and approved by the control agency, primary emphasis should be placed on how well and by whom these procedures were carried out. One recommended method of accomplishing this is a case by case review with those persons shown in the operational manual as being responsible for the control decisions. It is anticipated that the source operational manual will provide for some type of time and event logbook so that key steps in these control decisions are made a matter of record. In the event that such a logbook is not provided for in the source operational manual, the control agency should require it either by a revision to the operational manual or by separate written instructions to the source operator. If any of the personnel shown in the operational manual as being responsible for control decisions have been replaced during the period under review, the inspection team should examine the type of training provided to these replacement personnel and make a determination as to its effectiveness in the light of any control decisions which were made by them.

Just as control decisions must be made to curtail emissions, control decisions must be made to resume normal operations. This type of control decision should also be evaluated in the manner indicated above.

Figure 2-1. Basic Elements and Functions of a Supplementary Control System


Measured Threshold Values
Upgrade System
Operating Model
Control Decision
Time Delay
Controlled Emissions
Time Delay
Air Quality
Scheduled Emission Rate
Meteorological Inputs
Emission Monitors
Air Quality Monitors
Data Storage
Actual Meteorological Conditions
Control Agency
System Upgrade ● ● ● ●
Closed-Loop Mode △ △ △ △
Open-Loop Mode ○ ○ ○ ○
Data Storage — — —

Air Quality/Air Quality Monitors

Air quality is the measure of concentrations of a designated pollutant (in this case, SO_2) in the ambient air, averaged over certain periods. Air quality monitors are the sampling units employed to measure this ambient air quality. The first and overriding concern of the control agency is the determination that a violation of the SO_2 ambient standards has occurred or that there is a strong likelihood that it has occurred. The SCS operator has accepted responsibility for the air quality within a designated liability area and any violations of the NAAQS therein are his responsibility.

Actual measures of air quality are provided by the source operator to the control agency via monthly or weekly reports which show the hour by hour ambient concentrations of all stations in the SCS network. Independent corroborative measurements are obtained from the ambient monitors operated by or for the control agency. Based on the experience of agencies now exercising surveillance and enforcement of supplementary control systems such as the Puget Sound Air Pollution Control Agency in Tacoma, Washington, and the Texas Air Control Board in Austin, Texas, it is strongly recommended that the control agency operate its own monitoring network to complement and verify the monitoring network operated by a source authorized to use an SCS.

These ambient air quality monitors employ several different principles of operation including gas chromatography (with flame photometric detection), flame photometric, coulometric and colorimetric. Some conductimetric instruments will be referred to within the guideline since they are presently employed by some smelters, although EPA has not accepted this measurement principle as of the date of this publication. The ultra portable SO_2 analyzer referenced in Section 2.3.2 also employs the conductimetric principle, but this is not considered to be a disqualifying factor for its intended use. For further background on ambient monitors see Section 4.1 of Vol. 1 and Section 1 of Vol. II of these guidelines.

The SCS ambient air quality network at a source includes all permanent sampling stations and mobile/portable units described in the SCS operational manual. The location of these monitors should have been carefully evaluated prior to acceptance of the SCS, and they should represent the points of maximum expected ground level concentrations of SO_2. The relocation of any of these monitors by the SCS operator therefore, constitutes a change in the operational manual and is not acceptable without prior approval of the control agency. The source operator's plan of operation of the permanent monitors and his plan for the operation of portable or mobile ambient air monitors should also be specified in the operational manual.

In order to ensure that the location of the monitoring stations are constantly evaluated for optimum detection of maximum ground level concentrations of SO_2, it is recommended that the control agency conduct periodic surveys with ultra portable SO_2 monitors as described in Section 2.3.2. Observance of high SO_2 levels should be investigated and a determination made as to whether or not a permanent monitor should be established in that location.

Threshold Values

The closed-loop method of SCS operation can be considered as an "override" or emergency method of control in which control decisions are based on real-time measurements by the air quality monitoring network. An important element in the control decisions made in the closed-loop mode is the setting of threshold values for real-time ambient air quality for SO_2 - the idea being that if appropriate curtailment action is taken when these ambient concentrations are reached, the Ambient Air Quality Standards will not be exceeded. These measured threshold values may vary depending on the time of day or the location of the monitor, etc., and they may include criteria such as the rate of change in measured concentrations at an ambient air quality monitor. They will be specified in the operational manual and it should be noted that the failure of the source operator to take curtailment action when designated measured threshold values are reached, constitutes a violation of the requirement to follow the operational manual.

The open-loop method of SCS operation entails making emission control decisions based on calculations generated from the operating model in conjunction with either real-time or projected meteorological and emission data. It should be noted that in the open-loop method of control, predicted threshold values may be utilized as a factor in the operating model and in ensuing control decisions. These predicted threshold values should be specified as part of the operating model in the operational manual.

Time Delays

There are two types of time delays that are inherent in the normal operation of an SCS:

(1) The delay between the time that a control decision is made and the time that the ensuing curtailment action is implemented; and

(2) The delay between the time that a curtailment action is taken and the time that the action has an effect upon ambient air quality as measured at the ambient air quality monitors.

In certain cases, these time delays may allow for flexibility in exercising various options by which the control decisions may be implemented. For example, in order to achieve the require emission limitation for a predicted meteorological condition, TVA provides for a maximum allowable generation level and the time by which it must be attained. This feature allows the SCS operator the flexibility of employing the best option available to him, commensurate with his other responsibilities. Fuel switching for example, from high to low sulfur coal may require 6 to 10 hours but may be more desirable than load shifting under certain circumstances even though the latter may only require an hour or two.

Those time delays should be specified in the operational manual.

Upgrade System

This single element is in fact a review and evaluation of the key elements of the SCS with the objective of improving the overall reliability of the system to maintain NAAQS. It specifically includes evaluation of the operating model, meteorological prediction methods, threshold values, delay times, scheduled emission rate and data storage elements. The relationships between elements displayed in Figure 2-1 should also be examined. The examination of this element will normally be made only during a comprehensive inspection and is even broader in scope than that performed on the "control decision" element. In fact, it should be viewed as a review of the accumulated control decisions since the last comprehensive inspection, noting especially trends toward improving or worsening performance of the SCS.

Meteorological Inputs/Actual Meteorological Conditions

Meteorological Inputs include both the observation of certain meteorological factors at the time of emission release from the stacks plus the prediction of these parameters for some time into the future. These factors are some of the most important inputs to the operating model in the open-loop mode of SCS operation, since the model depends upon accurate real-time and predicted meteorological information in order to yield a control decision which will prevent the air quality standards from being exceeded.

Continuous meteorological data (wind speed and direction, temperature, and dew point) should be monitored at two levels in the lower air layer, e.g., measurements near ground level in a location not affected by downwash or other types of air flow distortion due to plant buildings or other roughness elements, and measurements at the top of the tallest stack. Measurements in the upper air layer will extend upward for several thousand feet above the top of the stack and can only be obtained periodically via remote sensing methods (rawinsondes, pibals, acoustic soundings, aircraft, etc.). These will provide information on stability and mixing height.

Upper air layer measurements should be routinely made at least twice in every 24-hour period (once in the early morning and once in the afternoon). The Tennessee Valley Authority (TVA) reports that at locations where SCS type operations are now being conducted, it is not unusual to have 3 of these measurements performed daily, either by rawinsonde or by weather aircraft.

A specific requirement of the operational manual is that it identifies the meteorological situations before and/or during which the emission rate must be reduced to avoid exceeding short-term NAAQS. Prominent in such situations are predictions of atmospheric stability, mixing height and wind direction and speed over the liability area surrounding the source stack(s). These meteorological predictions play a key role in the open-loop mode of SCS operation and source operators should be required to maintain a file of such predictions.

Scheduled Emission Rates/Controlled Emissions

The scheduled emission rate (or rates) for the source are identified in the operational manual for the designated processes and levels of operation of the smelter or power plant; the controlled emissions represent the emission rate(s) resulting from a control decision and are likewise identified in the operational manual. Any reported or measured emission rates in excess of those identified in the operational manual for specific conditions of operation are prima facie evidence that the operational manual was not followed.

Since the SCS regulations require the applicant to operate a measurement system for continuously monitoring SO_2 emissions and stack gas volumetric flow rates in each stack, the control agency must be provided with access to these readings. The review of these two elements is done in conjunction with the control decision element discussed above since the record of controlled emissions for individual decisions is an integral factor in the evaluation of the effectiveness of that control decision.

Measurement of these SO_2 emissions are made by monitors of either the extractive or non-extractive type and must be continuous (i.e. at least one sample or reading every 15 minutes). Extractive monitors are by far the most prevalent at the present time and employ a variety of operating principles, including:

- Colorimetric
- Conductimetric
- Coulometric
- Membrane diffusion potentiometric
- SO_2 fluorescent
- UV absorption spectroscopic

Non-extractive or in-situ emission monitors employ a principle of operation which is essentially spectrophotometric in nature. Refer to Section 4.2 of Vol. I and to Section 3 in Vol. II of these guidelines for more information on both types of emission monitors.

Operating Model

The operating model is best defined as a set of mathematical equations which relate meteorological inputs, emission rates, source data and terrain and location factors to current and future ambient air quality in the vicinity of the source. Since the applicant's operating model will have undergone careful scrutiny during the evaluation and preacceptance period, it can be assumed that potentially critical conditions have been accounted for in the model. The model is based on mathematical theories of atmospheric dispersion and turbulent diffusion and relates actual meteorological conditions, stack emission rates, and stack parameters (e.g. stack height, stack flow rate) to predicted ground level concentrations of SO_2 in the vicinity of the source.

The operating model is described in both the background study report and in the operational manual. The objective of any examination or review of this element is to determine if any of the parameters of the model have changed or if adherence to the conditions and actions specified by the model has not been effective in maintaining NAAQS in the designated liability area. The operating model is of greatest importance during the open-loop method of control since it determines the maximum allowable SO_2 emission rate for that source.

Data Storage

Data storage includes the cumulative records on emission rates, meteorological conditions and predictions, air quality measurements and control decisions. All such data must be available to the control agency. Specific records required to be kept by the source operator are described in the operational manual. In addition and depending on the type and amount of data which has been transmitted to the control agency on a weekly, monthly or continuous data telemetry basis, the control agency will have accumulated a significant amount of information on, and an understanding of, the source data storage system. Portions of this data storage system should be examined in varying degree during the inspections and reviews described in Section 3.

2.3 PORTABLE/MOBILE MONITORS AND ADDITIONAL METHODS OF SURVEILLANCE

2.3.1 Portable/mobile monitors are SO_2 monitors not permanently located within any network. They are used by the source operator and/or the control agency to:

1. Verify suspected points of high concentrations not being monitored by permanent stations.
2. Serve as part of the source's monitoring network described in the operational manual.

3. Verify source's monitor reading by duplicate siting of control agency's monitors.

Most of these monitors employ the same principle of operation as the ambient monitors discussed in Section 2.2 above; others may not employ a measurement principle acceptable to EPA, but are inexpensive, reasonably accurate, easy to operate and serve only as indicators of potentially high concentrations which must be followed up by more extensive monitoring.

It is recommended that the control agency use a number of portable/mobile monitors as an integral part of its surveillance of a supplementary control system. Complete and accurate data on ambient concentrations are essential to ensure that NAAQS are attained and maintained throughout the DLA.

2.3.2 Additional Methods of Surveillance

The monitors permanently sited as part of the source's air quality monitoring network, while yielding information at the points of maximum expected ground level concentrations, do not provide the control agency with information on air quality at points between the monitors. The control agency may therefore find it desirable or necessary to employ additional or alternative methods of surveillance to those described above. The remainder of this Section is devoted to a discussion of these methods for information and for implementation when feasible. In almost every instance these methods will not provide sufficient admissible evidence of a violation for penalty assessment purposes but they are valuable to the control agency as indicators of potentially high SO_2 levels where further monitoring should be performed.

Surveys with SO_2 Ultra Portable Analyzers

One alternate method that might be profitably employed by the control agency would be surveys or periodic patrols with SO_2 Ultra

Portable Analyzers. The Texas Air Control Board has effectively employed these in methodically surveying a large area rapidly to determine points of high concentrations. Follow-up measurements can then be taken by bubblers or other equipment to provide firm evidence of violations of ambient SO_2 standards.

Surveys or patrols with portable SO_2 monitors may be performed independently at random intervals during the year or they may be performed in conjunction with inspections. Most such patrols can be performed by one person and a portable monitor, hand carried or using a motor vehicle, depending on the nature of the terrain and the area to be covered.

Aerial Surveys

Aerial surveys to determine SO_2 concentrations are often employed by source operators and by various governmental air pollution control agencies. In some cases they are employed to examine the areas surrounding a source for discolored vegetation and/or to utilize remote sensing techniques to provide indications of high ground level SO_2 concentrations. In still other cases, they have been used to measure SO_2 at higher levels (e.g. 2000 feet above ground level) with the aid of portable SO_2 monitors. In either case, aerial surveys are important only insofar as they indicate the need for, and the nature of, further SO_2 monitoring at ground levels.

Discolored Vegetation

Large SO_2 sources have traditionally employed this method of detecting the results of high SO_2 surface concentrations after an episode. Complaints are investigated and claims settled on the basis of visual observation of the vegetation affected, such as a cash crop. It is difficult to determine whether the effects have been caused by a high concentration of short duration or by lower concentrations spread over a longer period of time.

This may not be considered an important enough method of detection for the control agency to devote manpower or other resources for routine patrols for this purpose, but discoloration noticed during routine inspections or aerial surveys should be investigated as an indication that excess concentrations of SO_2 may be appearing in those areas.

SECTION 3
INSPECTION/REVIEW PROCEDURES

3.1 COMPREHENSIVE INSPECTION

3.1.1 Introduction

The comprehensive inspection is in many respects the most important inspection. This inspection is designed to provide a thorough evaluation of the operation of the SCS and the operation and maintenance of all related monitoring equipment. It is especially useful when employed as a part of each required annual review of the source's use of an SCS and at such other times that the agency desires complete information on the operation of the SCS. It is expected that the control agency will require the services of 3 or 4 persons for 2 or 3 days to complete this inspection. (See Figure B-13 for example of task scheduling).

3.1.2 Preparation for Inspection

- Provide notification as required. A two week advance notice is sufficient to ensure that all necessary measurement records and other SCS operating data are available to the inspection team at the time of inspection.
- Compile a folder of reports made by the source operator to the control agency since the last inspection, including reported violation of NAAQS, emission standards or other violations discussed in Section 2.1 above. Reports in this folder will serve as a starting point for selection of dates for which a detailed data review is to be conducted.
- If the control agency operates its own ambient monitoring network in or near the DLA, compile a list of dates on which these monitors indicated ambient levels in excess of the NAAQS and of the threshold levels contained in the operational manual. This list will be used to evaluate and compare readings with those obtained from source network stations.
- Prepare and check out equipment shown in Appendix B, Figure B-15.

3.1.3 Inspection Procedures

Tasks include:

- Inspect instruments as shown below utilizing step-by-step procedures from Section 4 and Appendix B.
  - Two ambient monitors
  - Emission monitors on at least two stacks
  - One of each type of meteorological instrument, e.g., wind, temperature, humidity.
- Calibrate monitoring instruments as necessary - See Section 4.
- Check for proper location of permanent monitors and review plan and implementation of mobile monitoring.
- Check that the personnel responsible for the operation of the SCS as designated in the operational manual are present and are empowered to order emission curtailment actions without being overridden by upper management.
- Check for unreported changes in operational manual.
- Check for changes in stack height or authorized use of stack heaters.

  The authorized stack height(s) is (are) shown in the source operational manual. While it is unlikely that it will have been changed without the knowledge of the control agency during the period under review, any changes or contemplated changes to stack height(s) should be ascertained during this inspection. A determination should also be made at this time as to whether the source operator has begun to utilize or plans to install any stack heaters. Such heaters provide increased buoyant plume rise and as such could be a technical violation of the SCS regulation unless approved in the original application or in any subsequent revision.
- Inspect records (strip charts, log books, computer readouts) for any in-house reports of emission curtailment actions, ambient readings in excess of threshold values and NAAQS and emission rates in excess of those specified in the operational manual for particular meteorological and air quality situations. Note: The results of this combined list should be compared with those contained in the report folder prepared at the control agency office prior to the inspection. Any differences should be examined carefully, particularly those which indicate violations of SCS regulations not reported to the control agency. An example checklist for this type of inspection is presented in Figure B-1 of Vol. I of this manual.

3.2 SHORT INSPECTION

3.2.1 Introduction

The source operator is required to report any violation of ambient air quality standards to the control agency within 24 hours. This requirement will be an integral part of the SCS regulation and may also be contained in the source operational manual. On such occasions, the control agency should conduct a short inspection of the source to verify the nature and extent of the violation and to determine the exact causes for the violation. To be most effective, this inspection should be made as soon as possible after the report of violation has been received.

In that respect, the inspection will not be as lengthy as the comprehensive or the unannounced inspection. It is anticipated that it will be of brief duration (not more than one day) and will be conducted by a small inspection team of 1 or 2 people. Primary focus of the inspection will be those portions of the operational manual and the daily routine which may have contributed directly to the occurrence of the violation.

3.2.2. Preparation

The control agency will have little or no time to prepare for this inspection. It will be sufficient to briefly review the report of the last comprehensive inspection and the file of reported violations since that time. It is recommended that this report and file be taken by the control agency inspector on his visit to the plant for ready reference. Depending on the nature of the violation, he should gather together necessary equipment shown in Figure B-15.

3.2.3. Inspection Procedures

First priority of the inspection should be a review of the primary cause of the violation:

- failure of the CEC equipment
- inadequate or incorrect curtailment action
- uncalibrated equipment

Detailed tasks of the inspection team include:

- Examine CEC equipment and operating log to determine emission rates for 24 hours before and after the violation.

- Interview personnel involved in the control decision; verify that they are among those identified in the operational manual as authorized to make such decisions.
- Compare control decision made with that specified in the operational manual for the condition in question.
- If inspection determines that an emission or ambient monitor may be faulty - inspect that unit and its maintenance and operating log. Examine strip charts or other record for the 24 hour period prior to the violation for evidence of satisfactory operation and to determine if authorized emission rates or threshold values were exceeded during that time.

While this inspection is expected to be relatively brief, the control agency inspector(s) must recognize that a violation has reportedly occurred and that some type of penalties may result. It is essential therefore, that the inspection team gather factual evidence on the nature of the violation and on the circumstances surrounding the occurrence of the violation in order to support a subsequent enforcement action. Figure B-3 of Vol. I is a recommended checklist to be used for this type of inspection. During the course of the inspection, should it appear that conditions found are indicative of large scale violations of the procedures specified in the operational manual and in the SCS regulation, a more detailed inspection approaching that of the comprehensive type described in Section 3.1 above should be commenced immediately.

3.3 UNANNOUNCED INSPECTION

3.3.1 Introduction

The scope of an unannounced inspection falls between that of the comprehensive and the short inspections. Its distinguishing feature is that it be scheduled by the control agency with a minimum of advance notice.

This inspection is shorter in duration, requires fewer personnel than the comprehensive inspection and little or no equipment. None of the in-depth evaluations contained in the comprehensive inspection, such as the operator's efforts to upgrade the SCS, etc., are considered appropriate for the unannounced inspection. Since the comprehensive inspection will be announced well in advance and will presumably show the source at its best, it is recommended that the unannounced inspection be conducted during a weekend or other period when the source may be operating under somewhat relaxed conditions.

This inspection should provide the most realistic insight into such aspects of the source operator's routine SCS procedures as monitoring equipment maintenance and calibration, availability of designated personnel for making control decisions, correlation of production throughput with emission rates and ambient SO_2 readings, status of constant emission control equipment, source operator's data storage routine, and general evaluation as to control of fugitive emissions.

The inspection will require the services of 1 or 2 people for 2 days. It is recommended that at least one unannounced inspection of the source be conducted each year by the control agency.

3.3.2 Preparation

The control agency should prepare a time schedule for the 2 day period ensuring that the plant inspection and examination of monitors is scheduled to be done early on the first day. The inspection should also:

- Review the periodic reports on the SCS received from the source operator for the past 3 to 4 months for evidence of trends towards progressively higher readings at any monitoring stations.
- Review same records for excessive gaps in readings from ambient monitors, indicative of downtimes or other malfunctions at those stations. Any suspect stations should be scheduled for examination.
- Prepare and check out equipment shown in Figure B-15.

3.3.3 Inspection Procedure

Detailed tasks for completion by the inspection team include:

- Conduct plant inspection to determine operation of CEC equipment and extent of fugitive emission control.

- Inspect instruments as shown below utilizing the step-by-step procedures from Section 4 and Appendix B.
    - Two ambient monitors
    - One emission monitor
    - Two meteorological instruments
- Check for proper location of permanent monitors and check records for downtime.
- Determine presence of personnel authorized in the operational manual to order emission curtailment actions.
- Conduct zero and span checks on 2 ambient monitors and 1 emission monitor. If the results of the checks indicate differences in excess of 10% of those shown on the calibration curve, a multipoint calibration may be required. In the case of similar errors on the ambient monitors, faulty calibration of other monitors could be indicated, and the zero and span check should be extended to two or more of these monitors. If acceptable data is not obtained from these checks, full-fledged multipoint calibrations should be performed immediately by the control agency or scheduled as early as possible for all the monitors. Normally, a single point check (90% of the full scale setting) will suffice for the initial span checks performed during unannounced inspections.
- Inspect records (strip charts, log books, computer readouts) for randomly selected periods on those instruments appearing on lists described in Section 3.3.2 above. The objective of this record search is to determine occurrence of unreported violations of threshold values, NAAQS or authorized emission rates.

3.4 REVIEWS

3.4.1 Annual review

An annual review is required for each federally approved SCS to determine if use of the SCS should be continued or denied. The annual review is conducted by the control agency and requires the services of 2 or 3 persons for approximately 5 days. The review consists of:

1. A comprehensive inspection as described in Section 3.1 above to determine if the source owner or operator has developed and is employing a control program that is effective in preventing violations of the NAAQS.

2. An evaluation of the availability of Constant Emission Control (CEC) technology.

   The availability of constant emission control technology is a prime factor in determining whether or not a source operator can continue to operate an SCS. As indicated in Reference 1, appropriate senior officials of the source will have certified that they have investigated in good faith the availability of constant emission reduction methods as a precondition for obtaining approval to operate an SCS. The source operator is also responsible for providing to the control agency in the justification document and in the source operational manual a general description of the research investigations, or demonstrations that the owner or operator will conduct or support for the purpose of developing constant emission control technology applicable to his plant or complex. This description must include the resources to be committed, the qualifications of the participants and a description of the facilities and equipment to be utilized.

   In the case of federally enforceable rules, the determination as to availability of CEC technology will be made by the director of the state agency and/or the EPA Administrator. It will be based on the demonstration of technology which may be applicable to the case under consideration.

3. An evaluation of the source operator's performance in following any applicable compliance schedules for the installation of constant emission controls at the facility.

4. An evaluation of the good faith efforts of the source operator to follow the stated program for developing new constant emission reduction procedures which will be adequate to meet the national standards without the use of SCS. Specific items which should be examined are:

- Review Research Program

  Technical progress

  Dollars expended

  Personnel assigned

  Reports

  Future Plans

- Review Current Operations

  Summary of input materials (smelters only)

  Sulfur content of coal for combustion (power plants only)

Equipment operation and problems

Equipment modifications

Control of fugitive emissions

- Review Future Plans

  Equipment modifications

  New equipment

  Processing or combustion changes

  Material input changes (smelters only)

  Changes in sulfur content of combustion coal (power plants only)

  Pollution control systems changes

  Changes in fugitive emission handling systems.

In view of the complexity of the subject matter of constant emission controls, it is strongly recommended that the control agency maintain a continuous effort to keep itself appraised of the changes in the control technology for SO_2 emissions and to conscientiously monitor the research and development program of the source operator in order to ensure that he is keeping abreast of these changes. One way in which this can be done is for the control agency to maintain a current file of the technical literature on the subject and of reports of public hearings and court decisions on related cases. Reference (3) contains a summary of the background material for this portion of the review. The control agency should also avail itself of the SO_2 control technology information and data available through the appropriate EPA regional office. For specific short term needs of such information, the control agency may find it necessary to utilize the services of a consultant.

5. Review of Other Factors Which Resulted in Original SCS Approval

   This constitutes a brief review of the conditions which justified the approval of the original SCS application. Changes in these conditions may be sufficient cause for the control agency to deny continued use of the SCS. Section 3 of Reference 3 contains a description of the conditions which must be reviewed.

3.4.2 Review of Periodic Reports

The specific requirements and frequency of submittal of these reports will be described in the regulations promulgated for each respective source, but are expected to include:

- Hour by hour measurements of ambient air quality, emissions and meteorological parameters and other measurements as may be required.
- A summary of all places, dates and times when national (and state, if appropriate) ambient air quality standards for SO_2 were exceeded and by what amount.
- A summary report describing operations of the supplementary control system as defined in the operational manual and how the system will be improved.
- Change of name/function of key personnel

It is anticipated that these reports will be required monthly, or quarterly, although it is conceivable that the hour by hour measurements may be required weekly or more frequently under certain conditions (e.g. when there are increasing numbers of ambient air violations).

The hour by hour measurements should be examined carefully, particularly to note the frequency of ambient air SO_2 concentrations which exceed the threshold level. An increase in the number of these readings above the threshold values may be one of the first indications of a slackening of interest on the part of the source operator to guard against violations of ambient air standards.

The review of these reports will provide the control agency with its best information on the routine operation of the source. Reports should be reviewed as soon after receipt as possible, using forms B-4, 5 and 6 of Volume I. Reports concerning ambient air quality measurements should be reviewed for:

- Violations of air quality standards;
- Attainment of threshold values as defined in the source operational manual;
- Periods when data were not recorded or submitted and reasons why.

Any reports containing SO_2 emission data should be reviewed for:

- Scheduled emission rate - when it has been exceeded and by what amount;
- Periods when data were not recorded or submitted and reasons why;
- Emission estimates for these periods and reasons for downtime of emission monitors.

Meteorological data should be reviewed for achievement of values of wind speed, wind direction, mixing height, etc. which are described in the source operational manual as critical conditions requiring curtailment of operation.

The summary portion of this report must describe operations of the SCS for the time period concerned. These operations will include any control decisions made, and a report of any violations of air quality standards or of the SCS regulation itself during the period of the report.

SECTION 4

INSPECTION AND CALIBRATION OF MONITORING EQUIPMENT AND INSTRUMENTS

Monitoring associated with supplementary control systems can be grouped into three general categories:

- Ambient air monitors for SO_2
- Source stack monitors of SO_2 emissions
- Meteorological instruments

This section describes the general approach to be employed in the inspection and calibration of each of the three categories of instrumentation, providing background orientation, recommendations and rationale for the approaches selected. The step-by-step checklist for the inspection and calibration of all instrumentation is included in appropriate subsections below and in Appendix B.

4.1 AMBIENT SO_2 MONITORS

4.1.1 Inspection

Inspection of ambient SO_2 monitors should be conducted during each type of inspection described in these guidelines. The most thorough ones will be made during the comprehensive and unannounced inspections. For short inspections, only those monitors with expected high readings need be involved. Suggested calibration procedures for continuous ambient SO_2 monitors are contained in "A Guide for the Evaluation of Atmospheric Analysis" by Dr. P. Mueller et al (Ref. 4) or later revisions of that manual. Chapter 8 of that manual is included in Vol. II of this guideline for ready reference. In all cases, the Federal Reference Method for the Determination of Sulfur Dioxide in the Atmosphere (Pararosaniline Method) is to be used whenever the "referee method" is called for in Dr. Mueller's manual.

Regardless of the type monitor used, a general guideline for examining ambient SO_2 monitors is provided by this check list:

- The shelter must have 1) adequate working room; 2) adequate heating and air conditioning; 3) sufficient safe storage for reagents, gases and tools; 4) water, sewer and electricity adequate for all instruments and maintenance operations; 5) good housekeeping practices observed.

- The sampling probe and manifold must be of a material unaffected by SO_2 (e.g. borosilicate glass or quartz glass) and must be kept clean. The height of the probe should be at least thirty inches above the shelter roof and it should be of a length and diameter such that the volume flow rate is between 3 and 5 cfm and the mass flow through the manifold is 3 to 5 times greater than the sampling requirements of all instruments. Finally the shape of the inlet should be designed to minimize the amount of extraneous material which is introduced into the manifold, e.g. a "candy cane" or U-shaped intake.

- The instruments in use must use a method which has been judged equivalent to the Federal Reference Method. The monitors must also meet the suggested performance specifications (Reference 11, p. 8 and p. 39). Equivalent methods are listed on p.7 of this same manual and include Gas Chromatography (GC) Flame Photometric Detection (FPD), FPD detection, coulometric detection and colorimetric detection.

- Each monitor should be checked to ensure that:

  Exterior of monitor and components are clean;

  Plastic and rubber components are leak tight;

  Calibrated air flowmeter is providing constant flow;

  Calibrated liquid flow pump is providing constant flow (where applicable);

  All scrubbers have been regularly cleaned and refilled;

  Fuses are of correct size and functioning;

  All valves operate properly and have been cleaned regularly;

  Mercury columns in all thermometers are intact;

  pH of all reagents is within the accepted range (see manufacturer's manual);

  All cylinders of gases are of acceptable quality;

  Operation of recorders has been checked regularly, particularly for linearity;

  All maintenance and calibration logs are available for inspection as described in Section 3.1.9;

  Schedules for maintenance have been kept.

4.1.2 Calibration

The most important type of calibration for continuous SO_2 ambient monitors is the dynamic calibration. Prior to performing this however, a few preliminary operations should be conducted. The first one should be a precalibration check containing at least three points to detect any change in the slope of the calibration curve. A static check may be used as a check on the electronics and optics of an analyzer if the design so permits, but this type check may not be substituted for the required dynamic calibration. Finally, a check should be made of the calibration/maintenance records prior to the performance of a dynamic calibration. A dynamic calibration, as described below, must be performed at least at the frequency recommended by the manufacturer. Permanent records of the work done, signed by the staff performing the calibration and their supervisor, should include all strip charts, graphs and calculations made, as well as a thorough written explanation of the calibration. A list of items which should be included in this calibration/maintenance record is given on pages 86-81 of the Field Operations Guide for Automatic Air Monitoring Equipment (Ref. 11).

Dynamic Calibration Method for Ambient SO_2 Monitors

The calibration procedure for continuous SO_2 monitors recommended for use is the one published by Dr. Mueller, et. al., in "A Guide for the Evaluation of Atmospheric Analyzers" (Ref. 4). Section 2 of Vol. II of this guideline contains a detailed description of calibration procedures for automated ambient SO_2 analyzers. The Federal reference method is to be used wherever the "referee" method is called for in this reference. Specific points in this procedure requiring emphasis are:

1. The permeation tube should be equilibrated at the constant temperature to be used for a minimum of twenty-four hours.
2. The constant temperature bath must maintain the temperature of the air stream within 0.1°C and measuring thermometers must have this precision.

3. If permeation tubes are not used, the source and method of calibration of standard SO_2 mixture should be well documented.
4. Flowmeters should be calibrated at least monthly by an accepted method; i.e., a soap-film flowmeter for low flowrates; a wet test meter, a dry test meter, or a spirometer for flowrates above 10 ft^3/hr.
5. The diluent air or N_2 should either be free of SO_2, and other interferents such as NO_x or appropriate scrubbers should be attached to remove them.
6. All reagents should be prepared at the concentrations, the frequency and the manner prescribed by the Federal Reference Method, using chemicals of at least ACS Reagent Grade purity.
7. If the referee method is not used, the permeation tube must have been gravimetrically calibrated over a minimum thirty day reaction period.
8. If the referee method is used, a standardization of the spectrophotometer should be done concurrently with the calibration. All steps of the reference method must be conscientiously observed, particularly with regard to the length of time needed for color development.
9. Multipoint calibration means that six points, including the zero and span, are determined in replicate.
10. In examining strip charts of the calibration, sufficient time must have elapsed for a steady trace to have been obtained at each concentration measured. The manufacturer's manual specifies the recommended times which must elapse before steady traces are achieved at various concentrations.
11. The method of least squares should be used to define the calibration curve. The standard deviation of the curve should be calculated and compared with the standard deviation and slope of previous curves.
12. Any conversion factors from chart readings to ppm should be recorded in the calibration log.
13. If a static check was made, the results should have agreed within 10% of the results of the dynamic calibration.

4.1.3 Examination of Records from ambient SO_2 monitors

Examine records to ascertain that sensors have been continuously operated for sensing ambient air quality standards.

Data records should be available at least on summary sheets and on strip charts. The summary sheets, whether they have been prepared manually or by computer, should contain, as a minimum, hourly averages and daily maximums. An inspection of data should include the following items:

1. Prior to inspection, obtain background information sheets on the local agency (normally the control agency) on readings obtained from their system. This would include daily averages, monthly averages, number and dates of days exceeding threshold values, air quality standards and wind roses and other relevant meteorological data.
2. At the source, examine reports from the source operated network for:

   a) Amount and frequency of ambient SO_2 monitor downtime

   - about one hour per operating day will normally be required for zero and span checks. These checks should not be made during the time of day when high readings are anticipated or indicated.
   - additional downtime of ambient SO_2 monitors may result from normal maintenance of the monitors. Explanations should be available in logbooks (to be discussed in greater detail in Section 4.2). Overall, only 5-10% of the possible data should be lost due to equipment downtime. Maintenance should be scheduled so that only one monitor is disabled at any given time. Backup units should be available for substitute installation whenever a monitor is to be out of service over twenty-four hours. A multipoint calibration, as described in the Section 4.1.2 will generally require about eight hours.

   b) Internal consistency

   Examining the internal consistency of data involves cracking such factors as an upwind station's readings being lower than a downwind station's readings for the same period and adjacent stations having similar readings. The change in consecutive hourly average should be questioned if data differ by more than a factor of two.

   c) Consistency with data provided by the local agency

   Examining agreement between local agency data and source generated data should concentrate on days when high values would be predicted and days when high values were observed.

> For an annual check, twenty six days of data are sufficient (Ref. 14) for each station. Questions arising on auditing summaries should be answered by a thorough examination of the appropriate strip charts. Among items to check on a strip chart are:
>
> - zero drift
> - span drift
> - noise level
> - occurrence of spikes or high value peaks lasting less than ten minutes
> - accuracy of measuring the area under all peaks
>
> The permissible limits for drift and noise are defined in Ref. 11, p.8. Peaks of less than ten minutes duration may not be included in hourly averages (Ref. 4). Planimetering the area under any peak is a quick, accurate method of double checking questioned measurements.

Quality assurance guidelines have been set forth in "Guidelines for Development of a Quality Assurance Program, Reference Method for the Determination of Sulfur Dioxide in the Atmopshere," EPA - R4-73-028d (Ref. 12). The source operator should have a formalized plan for assessing the validity of data obtained and he should be able to demonstrate his use of the plan by selecting at least one month of raw data at random and then proceeding through all data verification checks.

As an example of data verification checks needed on a daily basis, the two highest hourly averages or the two most active hours should be reexamined by someone other than the person who originally reduced the data. If differences between any original and recalculated value exceed ± 3%, recalculate all hourly averages for that day. If hourly averages do not correspond to the source's predicted pattern, e.g., lowest values are obtained during night time hours, highest values are obtained when inversions are most probable (perhaps between 9 a.m. and 2 p.m.), the auditor should take the necessary steps to either verify these anomalies or reject them. Rejected data should be accompanied by the reason, e.g., excessive base line drift, excessive noise, power failure, etc. A final daily data report sheet should be issued and certified accurate by a knowledgeable, responsible staff member. During a comprehensive inspection these are the steps the source must be able to show they have followed.

4.2 SOURCE EMISSIONS MONITORS

4.2.1 Inspection

A thorough inspection of at least 2 SO_2 emission monitors together with a comprehensive review of all calibration and maintenance records and schedules should be performed during a comprehensive inspection. As noted in Section 2.2 there are several monitoring types and several manufacturers and models within each type. The guidelines which follow are referenced to the photometric type but similar criteria for inspection and calibration are applicable to other types of SO_2 emission monitors as well. Photometric SO_2 analyzers which extract and filter the gas sample (as opposed to those which have the detection cells within the stack) have a high degree of reliability and minimal downtime because the stack gas is confined to the optical absorption cell. Additionally there are no detection cells which require regular replacement. Detailed tasks for an inspection follow: (see Figure B-10).

- Check inlet filter and light source

  The frequency of the inlet filter change is determined by the particulate loading of the source gas and in the case of high particulate loading, might require changing daily. The light source should operate for months before replacement is required.

- Check Chiller

  Besides a filter, an extractive sampling system generally requires a chiller to condense water vapor from the sample so its dew point is below the temperature found in the optical cell of photometric analyzers. Unless carefully designed, the chiller can become plugged with ice, so a proven model should be used. Low sampling rates can occur due to plugging of the chiller or clogging of the inlet filter. A low sampling rate will degrade response time.

- Inspect optical systems

  In an inspection for proper operating procedure, one of the first things to check is the cleanliness of the optical system. Any dirt on or fogging of the sample cell windows will degrade performance. The flow rate through the instrument should also be checked to insure that the filter has not become clogged. If either of these conditions exist, it is an indication of inadequate maintenance.

- Check maintenance logbook

  The instrument should have a maintenance logbook and this should be checked to see that recommended maintenance has been performed. Calibrations with span gas should be noted in the log and should correspond with the instruments instruction book's recommendation. The span gases should be checked to determine that they cover the instrument's range and that the span gases bear certified analyses.

  If the instrument has two ranges, notation should be made on the chart paper anytime the range is changed. An abrupt change of level on the chart paper without such a notation should be suspect of an unmarked range change.

- Inspect plumbing system of instrument

  Since most photometric SO_2 analyzers aspirate their sample from the source, any leak in the plumbing leading to the optical cell will cause a low reading. A simple test for leaks is to plug the sample extractor and draw a vacuum on the sampling system. A vacuum gauge or manometer attached to the sampling system can then be observed to see if the system is leak tight. The sample inlet line should be heat traced FEP "Teflon" and could collapse if subjected to high vacuum. For this reason a vacuum of 10 inches of Hg will usually suffice for a leak check.

- Verify location of emission sampling point

  One important step in the inspection of all extractive types of continuous SO_2 emission monitors is to determine the location of the sampling point to ensure that it is representative of the average concentration in the duct. As specified in Reference (11) and elsewhere, the sampling point for monitoring the concentration of SO_2 emissions must be in the duct at the centroid of the cross section if the cross sectional area is less than 4.657 m^2 (50 ft^2) or at a point no closer to the wall than 0.914m (3 ft) if the cross sectional area is 4.657 m^2 (50 ft^2) or more. The monitor sampling point must be in an

> area of small spatial concentration in the duct. Information on the location of the sampling point will be contained in the log book for the source's emission monitor and should also be contained in the source operational manual. The actual location should be physically checked during a comprehensive inspection and during any unannounced inspection where the validity of the SO_2 emission readings may be in doubt.

This inspection should be performed by an individual who has had some practical experience in operating, maintaining or inspecting emission monitoring or ambient monitoring equipment plus some basic knowledge of optics. It will generally require such an individual one-half day to perform all the tasks described above for the inspection of an emission monitoring system of a source with one stack, exclusive of any span gas calibration checks which might be observed by the inspector or performed by him.

A more detailed description of some of these emission monitors can be found in Ref. 6. The section titled "Continuous Stack Gas Monitoring" has been excerpted from this manual and is included as Section 3 in Vol. II of these guidelines.

4.2.2 Calibration

Calibration procedures for continuous SO_2 emission monitors will be found in the maintenance and operating manuals published by manufacturers for their respective products. It is recommended that the control agency obtain a copy of the manual describing the type or types of emission monitor(s) employed by the source operator. In general, however, all extractive SO_2 emission monitors are calibrated in the same manner. Span and zero gases are connected to a 3-way T in the sample conditioning train ahead of any chilling or conditioning equipment. The stopcock of the T is turned to pass the zero gas first and when the analyzer has reached a steady reading, it is zeroed according to the manufacturer's instructions. A span gas which will give approximately 80% of the full scale reading is then passed into the T and it will continue to be passed until the analyzer has reached a steady reading. The span of the instruments is then adjusted so that the analyzer reads the concentration of the pollutant in the span gas. Additional span gases should then be passed through the system which will cause the analyzer to read at 20%, 40%, and 60% of full scale. Any deviation in the readings from the span gas composition should be noted, and used to plot a correction curve for use in analyzing the final data. Span gas may be supplied in cylinders with a certified analysis from the supplier. Note that permeation tubes are not recommended for the calibration of continuous SO_2 emission monitors.

In the case of the in-situ monitors the calibration is more difficult, sometimes requiring removal of the monitor from the stack. Although it may require a special set up, these monitors should be periodically calibrated with zero and span gases as in the case of extractive monitors. These in-situ monitors cannot be dynamically calibrated, but it is possible that they will be acceptable as a means for continuous SO_2 emission monitoring at some future date.

As indicated in Ref. 2, the control agency may specify that SO_2 emission rates must be determined using the referee methods given in the Federal Register (Vol. 36, No. 247, December 23, 1971) to corroborate the rates measured by the continuous SO_2 emission monitor. Such corroborative checks should be done at the start of the program and may be required at any time if consistently inaccurate results are suspected. The test method for continuous SO_2 emission monitors (Method 12) has not been promulgated as of the publication of this guideline, but a modified version of Method 12 has been published in Ref. 2 and Ref. 5.

Calibration of a typical emission monitor is estimated to require one half day per monitoring system.

4.2.3 Examination of records

Plant records should be examined to determine that emission monitors have been continuously operated. For continuous operations, the sensor recorder chart should have a continuous trace. Breaks in the trace should be labeled as to the nature of the problem. Emission monitoring equipment downtime should be calculated or estimated from the source operator's log books and should be approximately 2 or 3 percent over a 24 hour operating period. Downtimes above 5 percent should be questioned, together with downtimes which occur during critical periods (e.g. during or following any curtailment action).

4.3 METEOROLOGICAL INSTRUMENTS

Meteorological instruments are an integral part of any air monitoring program since meteorological data is extremely important for predicting air quality. Parameters with which to be concerned when dealing with supplementary control systems are wind speed and direction, temperature, precipitation, humidity, solar radiation, and the turbulence characteristics of the atmosphere (which include winds aloft and temperature lapse rate) to determine the dispersion capabilities of the air in the region.

4.3.1 Inspection

Meteorological instruments vary widely as to function, complexity and type. A detailed explanation of all the meteorological terms and measurement instruments discussed in this section and also in Section 2.2 can be found in Ref. 13 and also in Section 4 of Vol. II entitled "Meteorological Instruments" which is a subsection of a training manual on atmospheric sampling published by the Air Pollution Training Institute on the EPA (Course #435).

It is recommended that the inspection of a random sampling of these instruments be made using the check list in Figure B-11.

4.3.2 Calibration

Calibration of wind, temperature, and humidity instruments is usually simple since these instruments are typically not complicated.

Wind speed instruments, such as the cup anemometer, are first calibrated by the manufacturer in a wind tunnel where the wind speed is known. The instruments are then placed in the field and often are never recalibrated. It is assumed that if the instrument is running smoothly, it is producing accurate data. Periodic greasing of the bearings keeps the anemometer rotating smoothly. Those anemometers which require it are calibrated with a motor that will rotate the instrument at a known speed. The manufacturer should supply data as to which rotational speeds will correspond to which wind speeds.

Wind direction instruments are easily calibrated when installed. By turning the wind vane to a known direction heading, the recorder can be calibrated by determining the directional output of the instrument and making the proper adjustments of the recorder.

The recorders of these instruments can also be calibrated easily using known voltages as specified in the manufacturers handbook. By introducing a known voltage, and knowing what the corresponding output of the recorder should be, the recorder can be properly adjusted.

Radiosonde instruments, for determining temperature, pressure, humidity and winds aloft, are first calibrated by the manufacturer. These instruments are also calibrated before being sent aloft. The radio signal output is sent to the recorder and compared against the known values. Radiosondes are tracked by theodolites and readings are taken every thirty seconds to determine wind speed and direction aloft.

The radiosonde recorder is checked periodically by introducing a known radio signal to the recorder and comparing the output to the reference input.

Temperature and humidity instruments are periodically checked against reference instruments such as a mercury thermometer or a sling psychrometer.

4.3.3 Examination of records

Recorder charts are often used as indicators of the instrument response for calibration purposes. For example, a wind vane that rubs during rotation can be discovered by checking the charts. Abrupt changes in the wind direction pattern, appearing as step functions, are good indicators that unusual frictional forces are involved. Maintenance steps would then be called for.

Maintenance and calibration procedures are done routinely at different time intervals, ranging from daily checks to annual checks. The source operational manual should be checked for the proposed scope and frequency of these maintenance schedules. Reference 8 contains suggested calibration schedules and procedures for wind instruments and Reference 9 contains maintenance schedules and procedures for radiosonde and rawinsonde equipment. Reference 10 Engineering and Quality Control Inspections, discusses inspection techniques used by the National Weather Service.

REFERENCES

1) "Use of Supplementary Control Systems and Implementation of Secondary Standards", Federal Register,Vol. 38, No. 178, September 14, 1973 (40 CFR, Part 51).

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4) Muller, P.K., &. Tokiwa, E.R. de Vere, W.J. Wehrmeister, T. Belosky, S. Twiss, M. Imada, "A Guide for the Evaluation of Atmospheric Analyzers." EPA Contract 68-02-0214, June, 1973.

5) "Standards of Performance for New Stationary Sources - Primary Copper, Zinc and Lead Smelters." Federal Register, Vol. 39, No. 201, October 16, 1974.

6) "Source Sampling and Analysis for Gaseous Pollutants." Course No. 468, Air Pollution Training Institute - National Environmental Research Center, Vol. 39, No. 235, December 5, 1974.

8) National Oceanic and Atmospheric Administration, Weather Bureau Engineering Handbook, No. 8 Surface Equipment (EHB-8)

9) National Oceanic and Atmospheric Administration, Instruction Manual Calibration of Radiosonde Recording Equipment, Engineering Division Instruction Manual No. 9, (No. 9-415).

10) National Oceanic and Atmospheric Administration, Engineering Quality Control Inspections, National Weather Service Handbook No. 12, Publication (EHB-12).

11) "Field Operations Guide for Automatic Air Monitoring Equipment," EPA Contract CPA-70-124, October, 1972.

12) "Guidelines for Development of a Quality Assurance Program, Reference Method for the Determination of Sulfur Dioxide in the Atmosphere," EPA-R4-73-028d, August, 1973.

13) T.L. Montgomery et al, "A Simplified Technique Used to Evaluate Atmospheric Dispersion of Emissions from Large Power Plants" - Journal for Air Pollution Control Association 23 (5): 338-394, May 1973.

14) Guidance for Air Quality Monitoring Network Design and Instrument Siting OAQPS No. 1.2-012, U.S. EPA, January, 1974.

APPENDIX A

DEFINITIONS

1) Accuracy - The degree of correctness with which the measurement system yields the value of gas concentration of a sample relative to the value given by a defined reference method. This accuracy is expressed in terms of error, which is the difference between the paired concentration measurements expressed as a percentage of the mean reference value.

2) Actual meteorological Conditions - The measures of wind speed, wind direction, stability, mixing height, and other meteorological factors at the time of emission release.

3) Actual Emission Rates - The emission rate as measured by the in-stack emission monitors.

4) Air Quality Violation - A single ambient SO_2 concentration that exceeds a National Ambient Air Quality Standard (NAAQS) for SO_2 at any point within a designated liability area (DLA).

5) Analyzer - That portion of the measurement system which senses the pollutant gas and generates a signal output that is a function of the pollutant concentration.

6) Atmospheric Stability - A measure of the degree to which the atmosphere resists or enhances vertical motion.

7) Calibration Drift - The change in measurement system output over a stated time period of normal continuous operation when the pollutant concentration at the time of the measurement is the same known upscale value.

8) Calibration Error - The difference between the pollutant concentration indicated by the measurement system and the known concentration of the test gas mixture.

9) Closed-Loop Control - The SCS operational mode in which emission control decisions are based on real-time measurements by the air

quality monitoring network.

10) Constant Emission Controls (CEC) - Equipment or control systems which are permanent in nature and except for maintenance downtime are operating continuously to reduce or eliminate certain types of pollutants from stack emissions. For SO_2, these include wet scrubber systems and single and double absorption sulfuric acid plants.

11) Control Agency - Agency (local, state or federal) with responsibility over the source to ensure that the supplementary control system is operated in such a manner that the NAAQS are attained and maintained in the vicinity of the source.

12) Control Decision - Decisions, based on either the model prediction or real-time air quality (whichever dictates the lower emission rate), whether or not to continue with scheduled processes and their attendant emissions; and if not, how much to curtail the emission rate.

13) Critical Meteorological Conditions - Those meteorological conditions which are conducive to excessive ground level pollutant concentrations.

14) Data Recorder - That portion of the measurement system that provides a permanent record of the output signal in terms of concentration units.

15) Data Storage - Synchronous records of meteorological conditions, emission rate, model prediction, measured air quality, and control decisions available for control agency review and model upgrading.

16) Designated Liability Area - The geographic area where the ambient air quality is significally affected by emissions from the source.

17) Designated Personnel - Source personnel with responsibilities for adherence to the requirements of the SCS operational manual, including enactment of control decisions and to other regulatory requirements.

18) Dynamic Calibration - A performance test of the entire analyzer under simulated service conditions in which the response to a

calibrating gas over a known concentration range is determined. When reconciled with a static calibration, dynamic calibration also serves to verify 1) the correctness of reagent and sample air flow rates, 2) the efficiency of sample collection, 3) the integrity of the analyzer's plumbing, and 4) the quality of any reagents and/or reactants.

19) Fugitive Emissions - Emissions from a source which do not exit from a stack.

20) Gravimetric Calibration - A method of calibrating losses or gains on a weight basis. Permeation tubes are originally calibrated gravimetrically.

21) In-Situ Emission Monitors - Stack emission monitors that will analyze the flue gas without removal of the flue gas from the stack.

22) Inversions - A reversal of the normal atmospheric temperature gradient, thus an increase of temperature of the air with increasing altitude.

23) Meteorological Inputs - Observations and predictions of the values of meteorological variables required by the operational model to determine the degree of control needed to avoid threats to the national standard (e.g. wind speed, wind direction, stability, mixing height).

24) Multipoint calibration - A dynamic calibration of an instrument involving the determination of response of the monitor to pollutant concentrations equivalent to 0%, 10%, 20%, 40%, 60% and 80% of the instrument's range.

25) Neutral atmospheric conditions - A deviation from the normal atmospheric temperature gradient where the potential temperature remains constant with increasing altitude.

26) Noise Level - Spontaneous deviations from a mean output not caused by input concentration changes.

27) Open-Loop Control - The SCS operational mode in which emission control decisions are based on calculations using the operating model in conjunction with either real-time or projected meteorological and emission data.

28) Operating Model - A set of mathematical equations which relates meteorological inputs, emission rates, source data and terrain and location factors to current and future ambient air quality in the vicinity of the source.

29) Operational Period - A minimum period of time over which a measurement system is expected to operate within certain performance specifications without unscheduled maintenance, repair or adjustment.

30) Planimeter - A mechanical device for determining the area of irregular figures. The area is determined by tracing the perimeter of the irregular figure with the planimeter.

31) Response Time - The time interval from a step change in pollution concentration at the input to the measurement system to the time at which 95 percent of the corresponding final value is reached as displayed on the measurement system data presentation device.

32) Sampling Interface - That portion of the measurement system that performs one or more of the following operations: delineation, acquisition, transportation, and conditioning of a sample of the source effluent or protection of the analyzer from the hostile aspects of the sample or source environment.

33) Scheduled Emission Rates - The emission rate which would result under the currently scheduled processes and levels of operation.

34) Source Operational Manual - The operating manual for the SCS at that source. It must be submitted by the source and approved by the control agency. It contains all essential information on the SCS including a full description of the ambient, emission and meteorological networks; an identification of meteorological situations and monitor readings requiring curtailment actions; identification

of source personnel involved in control decisions; and a description of the source operator's program for systematically evaluating and improving his SCS.

35) Span Drift - The change in instrument output over a stated period of unadjusted continuous operation, when the input concentration is a stated upscale value.

36) Span Gas - A calibrating gas containing a pollutant concentration equal to some up-scale value, usually 80% of full scale.

37) Stagnation - Little or no mixing of the atmosphere for pollutant dispersion, usually due to lack of wind.

38) Static Calibration - The determination of the analyzer response when artificial stimuli such as standard calibrating solutions, resistors, screens, optical filters, electrical signals, are applied directly to the analyzer detector. It is a performance test of the detection and signal presentation components of the instrument and is primarily applicable to analyzers using colorimetric and conductimetric detectors.

39) Temperature Lapse Rate - The rate of change of temperature with increase in height.

40) Threshold Values - Measured concentration levels somewhat below air quality standards and/or rates of change of concentrations that serve as indicators of potential violations of the standard. They are selected so that a control decision for emission reduction can be made in sufficient time to prevent air quality standards from being violated.

41) Time Delays - Time will be required to implement the control decision, and more time will pass before the reduced emission rate affects air quality at a distance from the source.

42) Upgrade Systems - A periodic evaluation of all system parameters (including the operating model, the meteorological prediction methods, threshold values and other control criteria), based on

stored data, with the objective to improve the system's reliability in maintaining the national standards.

43) Wind Rose - Any one of a class of diagrams to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction. The most common form consists of a circle from which eight or sixteen lines emanate, one for each compass point. The length of each line is proportional to the frequency of wind from the center. Many variations exist. Some indicate the range of wind speeds from each direction; some relate wind direction with other weather occurrences.

44) Zero Drift - The change in instrument output over a stated time period of unadjusted continuous operation, when the input concentration is zero.

45) Zero Gas - A gas containing less than 1 ppm of sulfur dioxide for an emission monitor and 0.01 ppm for an ambient monitor.

Appendix B

Inspection Forms, Checklists and Schedules

A variety of suggested forms, checklists and schedules are included in this appendix to assist the control agency in performing the tasks associated with the surveillance and enforcement of supplementary control systems. These forms and checklists are representative of the ones required by control agencies and are not intended to cover all requirements of each individual agency. Explanation of entries on individual forms are contained in Section 3 of Vol. I.

FIGURE NUMBERS

B-1 Comprehensive Inspection - suggested inspection forms

B-2 Unannounced Inspection - suggested inspection forms

B-3 Short Inspection - suggested inspection forms

B-4 Review of periodic reports (weekly or monthly)

B-5 Information on individual control decision

B-6 Evaluation of control decision

B-7 Inspection of ambient SO_2 continuous monitors

B-8 Zero and Span check for ambient SO_2 continuous monitors

B-9 Multipoint calibration of ambient SO_2 continuous monitors

B-10 Inspection of SO_2 continuous emission monitoring instruments

B-11 Calibration and inspection of meteorological instruments

B-12 Comprehensive Inspection - personnel/time estimates

B-13 Schedule for comprehensive Inspection

B-14 Personnel/time estimates for unannounced inspections and short inspections

B-15 Equipment required by control agency for inspection

B-16 Maintenance checklist for ambient SO_2 continuous monitor

FIGURE B-1

COMPREHENSIVE INSPECTION - suggested Inspection Form

PLANT ______________________________ DATE __________________________

ADDRESS ____

PLANT CONTACT(S) & TITLE(S) ____________________________________

____

INSPECTORS ____

METEOROLOGICAL INPUTS /ACTUAL METEOROLOGICAL CONDITIONS

Check if critical meteorological values were reached. If so, record values plus dates and times values occurred.

Check for control decisions enacted at time (or before) critical meteorological values reached. (See Figures B-5 and B-6)

Check meteorological instruments as outlined in Calibration and Inspection of Meteorological Instruments, (Figure B-11)

OPERATING MODEL

Check if operating model correctly identified critical atmospheric conditions.

Check surrounding terrain for variation from original model data due to construction, grading, excavating, etc.

Determine relative frequency of occurrence of closed-loop mode of operation.

Verify stack height(s)

SCHEDULED EMISSION RATE

Check charts and records of emission monitoring equipment to determine if the scheduled emission rate was exceeded (See Figure B-5)

Check emission monitoring instruments as outlined in Figure B-10, Inspection of SO_2 Emission Monitoring Instruments.

FIGURE B-1 (continued)

CONTROL DECISION

Check what control decisions were enacted and what prompted the enactment of each decision (see Figure B-6)

Check if authorized or expected personnel made the appropriate control decision.

TIME DELAYS

Check and record time delays from the acknowledgement of threshold values to the enactment of control decisions.

Check and record time delays from the enactment of control decisions to the reduction of the threshold values.

AIR QUALITY

Check charts and data (source and control agency) for any violation of SO_2 ambient standards in the designated area. Record dates and times of all occurrences. Compare against reported SO_2 standard violations.

AIR QUALITY MONITORS

Check for relocation of air quality monitors. If monitors have been relocated, check for justification and evaluation by appropriate control agency.

Check records of mobile/portable monitors for high readings. Check if additional monitoring by mobile/portable monitors resulted from these high readings.

Check ambient SO_2 instruments as outlined in Figure B-7, Inspection of Ambient SO_2 Continuous Monitors.

THRESHOLD VALUES

Check if appropriate curtailment actions were carried out when ambient

FIGURE B-1 (continued)

SO_2 threshold values were reached. Record dates and times of threshold values and the corresponding action taken (see Figures B-5 and B-6)

DATA STORAGE

Check if required records are kept and are in order. Check accumulated charts and data for completeness. Refer to Subsection 3.1.10

Check accumulated records for trends in the increase or decrease of emission rates, production rate, ambient SO_2 levels, etc.

UPGRADE SYSTEM

Check and suggest factors that may be useful in upgrading SCS system. This may include evaluating the operating model, meteorological prediction methods, threshold values and delay times. Refer to Figure B-6.

FIGURE B-2

UNANNOUNCED INSPECTION - Suggested Form

PLANT ______________________________ DATE ________________________

ADDRESS ____

PLANT CONTACT(S) & TITLE(S) ____

____

INSPECTORS ____

SCHEDULED EMISSION RATE

Check scheduled emission rate and compare to allowable emission rate defined in the plant's operational manual.

Check emission monitoring instruments as indicated on Figure B-10, Inspection of SO_2 Continuous Emission Monitoring Instruments.

CONTROL DECISIONS

Check if authorized or expected personnel made the appropriate control decision.

Check control decisions made. Record decisions, dates and personnel responsible for decision. Compare with decisions required. (See Figure B-6).

METEOROLOGICAL INPUTS

Check and report upon the condition of the meteorological instruments. Figure B-11, Calibration and Inspection of Meteorological Instruments, can be used. (Inspection need not be as extensive as in other reviews.)

AIR QUALITY

Check charts and data (source and control agency) of SO_2 instruments to determine if any violation of ambient standards has occurred.

Check air monitors as outlined in Figure B-7, Inspection of Ambient SO_2 Continuous Monitors.

FIGURE B-2 (Continued)

THRESHOLD VALUES

Check charts and records for approach or attainment of threshold values. Record control decisions enacted to avoid threshold values and comment on their actual effectiveness. (See Figure B-6).

DATA STORAGE

Check data and records for completeness. Check accumulated data for availability and ensure data is up to date.

FIGURE B-3

SHORT INSPECTION - Suggested Form

PLANT ______________________________ DATE ______________________________

ADDRESS ____

PLANT CONTACT(S) & TITLE(S) ____

____

INSPECTORS ____

Describe nature of violation including date, time and duration of occurrence.

SCHEDULED EMISSION RATES

Check scheduled emission rate for exceeding allowable rate defined in the plant's operation manual. Record actual emission rate and compare to allowed emission rate.

CONTROL DECISION

Check control decision and factor(s) prompting each control decision. Compare these control decisions to required control decisions to attempt to determine cause of violation. (See Figure B-6).

METEOROLOGICAL INPUTS

Check meteorological data for critical values approached before notice of violation. Check control decision(s) enacted.

TIME DELAYS

Check time delay from the notification of critical or threshold values to the enactment of the corresponding control decision.

Check time delay from the enactment of the control decision to the reduction of the threshold values.

AIR QUALITY

Check air quality instruments as outlined in Inspection of Ambient SO_2 Continuous Monitors, Figure B-7. At a time of violation emphasis should be on the data. It may not be necessary to even visit any sites if charts are available in a central location.

THRESHOLD VALUES

Check critical threshold SO_2 values to determine what corresponding control decisions were enacted (this is an attempt to determine the cause of the violation). (See Figure B-6).

DATA STORAGE

Check if required records are kept and are in good order. Check accumulated charts and data for completeness.

FIGURE B-3 (Continued)

SHORT INSPECTION - Suggested Form

PLANT ______________________________

LOCATION ______________________________

MANAGER ______________________ OTHER RESPONSIBLE ____________________

STAFF ______________________________

VIOLATION DATE __________________ HOURS ____________ COMPLAINTANT __________

INSPECTION DATE _________________ HOURS ____________ INSPECTORS ____________

STANDARDS VIOLATED	AGENCY	SOURCE

AMBIENT MONITORS RECORDING VIOLATION	LOCATION	TIME	VALUE

OTHER INDICATIONS OF EXCESSIVE EMISSIONS ______________________________

METEOROLOGY	WIND DIR.	WIND SPEED	TEMP.	R.H.	OTHER

SOURCE EXPLANATION FOR EXCESSIVE EMISSION ______________________________

____

REMEDIAL ACTION TAKEN ______________________________________

VIOLATIONS INCURRED ____

(Attach copies of data from all ambient air monitors showing threshold values of SO_2 to have been exceeded).

FIGURE B-4

SCHEDULED REPORTS (WEEKLY OR MONTHLY) - Suggested Contents

The following subjects should be covered in the weekly (or monthly) reports:

SCHEDULED EMISSION RATE

Discussion and data should be supplied to show that the allowable emission rate, defined in the operators manual, has not been exceeded.

Information on any problems or non-routine maintenance that must be performed on the emission monitors should be supplied.

CONTROL DECISIONS

Information should be included concerning any control decisions that were made since the previous report period. Information on the factors that preceded the control decision should also be included.

AIR QUALITY

Data on the approachment of the ambient air quality standards should be supplied (high and low values for the report period, mean value etc.)

Information on any drastic or non-routine maintenance of the air quality monitoring instruments should be included.

THRESHOLD VALUES

Any approach or attainment of defined threshold values should be discussed. The control decisions enacted to avoid these threshold values should also be included.

DATA STORAGE

Data should be included to show that records are being kept up to date and in good order. Accumulated records should also be shown to be in order.

FIGURE B-5

INFORMATION ON INDIVIDUAL CONTROL DECISIONS

1. RECEIPT OF ACTION INFORMATION (DATE & TIME)

Critical Meteorological Conditions Predicted ____________________

Critical Meteorological Conditions Reached ____________________

Threshold Levels of Ambient SO_2 Concentrations Attained ____________________

SO_2 Emissions in Excess of Authorized Rate ____________________

Other (e.g. sulfuric acid plant failure, etc. - Describe ____________________

____

____

2. ACTION TAKEN	TIME WHEN ORDERED	BY WHOM
Curtailment		
Load Shift		
Fuel Change		
Other (Described)		
3. ACTION COMPLETED		

4. LEVELS REACHED	MAX. READING	STATION #	TIME
Emission Levels Reached			
Ambient Levels Reached			

5. NORMAL OPERATIONS RESUMED	TIME WHEN ORDERED	BY WHOM	TIME WHEN NORMAL LEVEL ATTAINED

6. COMMENTS ____________________

____

____

FIGURE B-6

EVALUATION OF CONTROL DECISIONS Suggested Form

Dates Predicted Critical Meteorological Values Observed	Dates Air Quality Standards Exceeded	Control Decision Ordered (describe)	Results	Responsible Personnel	Evaluation of Control Decision

FIGURE B-7

SUGGESTED FORM: INSPECTION OF AMBIENT AIR QUALITY MONITORING INSTRUMENT.

PLANT: ______________________ DATE: ________________

ADDRESS: ______________________ INSPECTOR: ______________

CONTACT: _________________ TITLE: _______________

MONITOR: ____

Site Instrument Principle of Operation

1. Check cleanliness of shelter, monitor, components, recorder and probe
2. Check heating and cooling of shelters for adequacy
3. Check condition of valves and related components
4. Check condition of all tubing
5. Check condition of all air scrubbers and filters
6. Check calibration frequency of air flowmeter
7. Check constancy of air flow
8. Check calibration frequency of liquid flow pump where applicable
9. Check constancy of liquid flow where applicable
10. Check condition of all reagents: age, storage, care of hazardous chemicals, etc.
11. Check source of gases and certification of analyses
12. Check settings of instruments against settings recorded in last calibration
13. Check format, content and completeness of logbook
14. Check frequency of zero and span checks
15. Check strip charts for excessive baseline drift and noise
16. Check strip charts for readings exceeding threshold values and/or standards
17. If necessary, perform zero and span checks and/or multipoint calibration of instruments (see attached form).

FIGURE B-8

SO_2 CONTINUOUS AMBIENT MONITOR ZERO AND SPAN CHECK - Suggested Form*

INSTRUMENT ______________________ DATE ____________________

LOCATION ______________________ ANALYST __________________

PLANT ______________________

ADDRESS ____

INSTRUMENT SETTINGS

RANGE ______________________ AIR FLOW ________________________

BASELINE ______________________ LIQUID FLOW ______________________

CONVERSION FACTOR FROM RECORDER READING TO PPM ________________________

ZERO CHECK

ZERO READING ____________________

DIFFERENCE FROM ORIGINAL SETTING ____________________________________

ACCEPTABLE ZERO (YES OR NO) __________________________

SPAN CHECK

SOURCE OF SPAN GAS _______________________

CONCENTRATION OF SPAN GAS ________________

RECORDER READING ________________________

EQUIVALENT PPM __________________________

DIFFERENCE FROM ORIGINAL SETTING __________

ACCEPTABLE SPAN (YES OR NO) ______________

---

* For unannounced or short inspections.

FIGURE B-9

SO_2 CONTINUOUS MONITOR MULTIPOINT CALIBRATION - Suggested Form

INSTRUMENT ______________________ DATE ____________________

LOCATION ________________________ ANALYST __________________

PRE-CALIBRATION CHECK

INSTRUMENT SETTINGS

RANGE ________ SET AIR FLOW __________ ACTUAL AIRFLOW __________

BASELINE ______ SET LIQUID FLOW ________ ACTUAL LIQUID FLOW _______

CONVERSION FACTOR-RECORDER READING TO PPM ________________________

INPUT _________ PPM INSTRUMENT READING ___________PPM

DEVIATION ________% does deviation exceed 10% Yes/No

CALIBRATION

INSTRUMENT SETTINGS LIQUID FLOW ____________

BASELINE ____________ RANGE __________ AIR FLOW _______________

Permeation Tube Output	Dilution Airflow	Sample Gasflow	Sample Time	Recorder Reading	SO_2 Conc.	Absorbance of Impinger Sample	SO_2 Conc.

CALCULATIONS

Attach graph of actual SO_2 concentration vs. Recorder Response. Use method of least squares to obtain best-fit straight line.

FIGURE B-10

INSPECTION OF SO_2 CONTINUOUS EMISSION INSTRUMENTS - Suggested Form

PLANT ____________________ DATE __________

ADDRESS ____________________ INSPECTOR __________

CONTACT ________________ TITLE ______________

MONITOR ______________________________________

Site Instrument Principle of Operation

1. Check cleanliness of shelter, monitor, components, recorder and probe
2. Check heating and cooling of shelters for adequacy
3. Check condition of sample conditioner and related components
4. Check condition of all tubing for condensation and loose fittings
5. Check condition of all particulate filters
6. Check calibration frequency of sample flowmeter
7. Check constancy of sample flow
8. Check for proper location of sampling point for monitoring emissions
9. Check calibration of frequency of liquid flow pump where applicable
10. Check constancy of liquid flow where applicable
11. Check condition of all reagents: age, storage, care of hazardous chemicals, etc.
12. Check source of zero and calibration gases and certification of analyses
13. Check settings of instruments against settings recorded in last calibration
14. Check format, content and completeness of logbook
15. Check frequency of use of zero and span checks
16. Check strip charts for excessive baseline drift and noise
17. Check strip charts for readings exceeding threshold values and/or standards
18. If analyzer has dual range, check strip charts to see that the range used is indicated on chart.
19. Perform zero and span checks and/or multipoint calibration to detect leaks in sampling system.

FIGURE B-11

CALIBRATION AND INSPECTION OF METEOROLOGICAL INSTRUMENTS - Suggested Form

PLANT ______________________________ DATE ______________________________

ADDRESS ____

PLANT CONTACT(S) & TITLE(S) ____

____

INSPECTORS ____

INSTRUMENT INSPECTION

1. Check wind speed instruments for smooth rotation; check date of last time bearings were lubricated.
2. Check wind vanes for frictional errors
3. Check temperature recording devices with a mercury thermometer
4. Check humidity recording devices with a sling psychrometer
5. Describe any errors determined during calibration check

DATA INSPECTION

1. Check all charts for continuous instrument operation
2. Check wind charts for smooth transition curves
3. Check log book for adherence to calibration and maintenance schedules
4. Check charts and record corresponding dates on the occurrences of critical meteorological values (See Figure B-6)
5. Describe any variations from expected data values.

FIGURE B-12

COMPREHENSIVE INSPECTION - personnel/time estimates

2 Men - 2 days - Calibration Team (Maybe 1 man 2½ days)

1) Air Monitor Calibration - (assume 2 instruments) 1 day/instrument

2) Source Monitor (assume 1 instrument) 1 day (or ½ day)/instrument

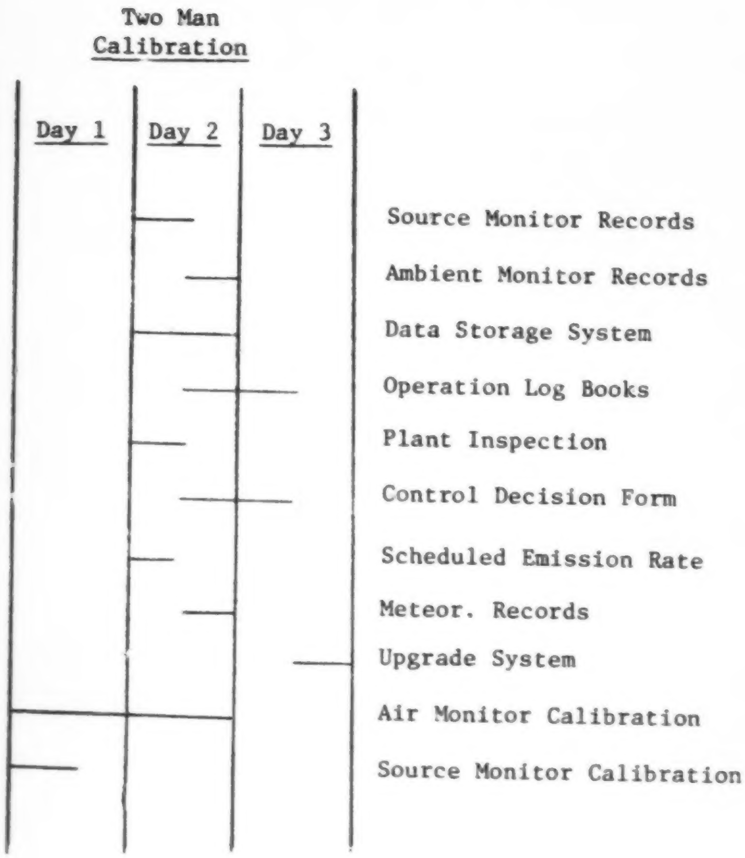
Inspection Team 4 Men	4 Men 2 days
Source Monitor Records Ambient Monitor Records	1 Man 1 Day (1)
Data Storage System	1 Man 1 Day (2)
Operations Log Book Plant Inspections Control Decision Evaluations	1 Man 1½ Days (3)
Schedules Emission Rate Meteorological Records Operations Log Book	1 Man 1½ Days (4)
Upgrade System	4 Men ½ Day (1) (2) (3) (4)

NOTE:

Numbers in parenthesis above refer to personnel of inspection team; i.e. member number 1 is (1) etc.

FIGURE B-13

SCHEDULE FOR COMPREHENSIVE INSPECTION



Note: Lines represent typical time intervals necessary for individual tasks. Some tasks such as the inspection of operation log books and completion of control decision forms can be carried on simultaneously. Also if permeation tubes are used for calibration of air monitors, they must be equilibrated in each location for a period of time before they can be used. During such "waiting" periods, that particular inspector can be utilized for inspection of records or other tasks.

FIGURE B-14

Personnel/time estimates

1. UNANNOUNCED INSPECTION

2 Men - 2 Days

Scheduled Emission Rate & Emission Monitors	1 Man, 1 Day (1)
Air Quality & Monitors & Records	1 Man, 1 Day (1)
Threshold Values Data Storage	1 Man, 1 Day (2)
Meteorological Data & Instruments Control Decisions	1 Man, 1 Day (2)

2. SHORT INSPECTION

2 Men - 1 Day

Control Decisions Time Delays	1 Man, ½ Day (1)
Air Quality Monitors and records Scheduled emission & Emission Monitors Meteorological data and monitors	1 Man, 1 Day (2)
Data Storage Threshold Values	1 Man, ½ Day (1)

NOTE:

Numbers in parenthesis above refer to personnel of inspection team; i.e. member number 1 is (1) etc.

FIGURE B-15

Equipment required by control agency for inspections

	Comprehensive	Short	Unannounced
Permeation tube	x		%
Dilution Board	x		%
Zero Gas	x	x	x
Span Gas	x	x	x
Diluent Gas	x	x	%
Solutions	x		%
Spectrophotometer	x		%
Portable SO_2 Analyzer	x		
Planimeter	x	x	x
Tubing for Connections and sampling lines	x	x	x
Voltage meters	x		x
Tool Kit	x	x	x
Mercury Thermometer	x		x
Sling Psychrometer	x		x
Compass	x		x
Stop Watch	x		%
Thermocouple	#		
Pitot tube	#		

# Required if stack emission rate is in question.

% If calibration of equipment is performed.

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FIGURE B-16

MAINTENANCE CHECKLIST

LEEDS & NORTHRUP AEROSCAN SULFUR DIOXIDE MONITOR

Serial No. ____________________

Item	Description	Check ✓	Date	Technician
1.	Prior to maintenance, check the instrument as it was used in the field: Calibration check after ______ months in the field. Instrument read ________ pphm when it should have read ________ pphm. Percent of error = __________ %.			
2.	All glassware has been cleaned in chromic acid.			
3.	Flowmeter has been cleaned in alcohol			
4.	All rubber tubing connections have been replaced.			
5.	All tubing has been cleaned or replaced. Stopper is in good condition			
6.	Conductivity cells have been re-platinized according to correct procedure.			
7.	Conductivity cells have been checked on bridge and matched. #1 = __________ mhos, #2 = __________ mhos.			
8.	Zero control solenoid has been disassembled and cleaned.			
9.	Air flow control assembly has been disassembled and cleaned.			
10.	There are no brass fittings between the inlet line and internal glassware			
11.	Pump has been disassembled, checked for wear, cleaned, lubricated and worn parts replaced.			

L & N Aeroscan Sulfur Dioxide Monitor

Item	Description	Check ✓	Date	Technician
12.	Soda lime scrubber has been cleaned and refilled			
13.	Cabinet interior and exterior is clean			
14.	Fuses have been inspected and are of proper size. Amplifier = .5 amp., Sigma pump = .6 and 1.0 amp.			
15.	Meter reads 0 when instrument is off			
16.	All five switches function properly			
17.	Zero control solenoid has been checked for leaks			
18.	Cabinet fan operates smoothly			
19.	Air line valve operates smoothly			
20.	Instrument air bypass valve has been disassembled and cleaned			
21.	Air flow has been checked at 40, 60, and 80 on flowmeter. Curve is drawn, set point for 4.7 l/min.= ____________ on flowmeter.			
22.	Liquid flow has been checked at 50, 75, 100%, and curve drawn. Set point for 1.5 ml = ____________			
23.	Liquid flow checked at 100% = ____________ ml/min.			
24.	All indicator lamps are operational			
25.	Cabinet thermometer mercury column is not separated			
26.	Instrument chamber temperature is $120^\circ + 1^\circ$ F. Actual temperature ____________ F°			
27.	Record Check 1 and Check 2 for thirty minutes each. Check 1 = ____________, Check 2 = ____________.			

L & N Aeroscan Sulfur Dioxide Monitor

Item	Description	Check ✓	Date	Technician
28.	No bubbles are in the reagent line			
29.	Instrument has been checked on zero for sixteen hours. Drift is less than one percent. Noise level is ______% (Should be less than 1% with no spikes or deviations)			
30.	Instrument has been calibrated at about 25%, 50%, 75%, and 100% of span			
31.	Instrument has been labeled as to correct air and liquid flow settings and next calibration date			
32.	Instrument has been checked on span gas for sixteen hours. Noise level is ______%. (Should be less than 3%			
33.	The following charts have been turned in with the maintenance check list: 1. Chart showing 16 hours of zero and 16 hours of span, 2. Chart showing instrument calibration, 3. Chart showing the zero and span check when the instrument was brought in from the field			
34.	Analog charts have been cut, in 24-hour periods, from 0000-2400 and are arranged sequentially. Charts are Identified as follows: Date (Month, day, year) (Day of week) "Calibration of L & N Aeroscan," Serial No. DOE No. Pollutant and range Signature of operator In addition, all periods for which the data deviates from normal or is invalid has been explained. A true time position (PST) is marked on each chart daily.			
35.	REMARKS:			

GUIDELINES FOR ENFORCEMENT
AND SURVEILLANCE OF
SUPPLEMENTARY CONTROL SYSTEMS

Volume II

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SECTION 1

PRINCIPLES OF MEASUREMENT EMPLOYED BY VARIOUS SO_2 AMBIENT AIR MONITORS

1.1 CONDUCTIMETRIC

This method measures the SO_2 concentration in ambient air by bubbling the air into a conductivity cell containing dilute hydrogen peroxide or deionized water. In the instruments using hydrogen peroxide, the SO_2 is absorbed by the solution and oxidized to sulfuric acid. Sulfuric acid completely ionizes in solution to form the highly conductive species H^+ and HSO_4^-. The presence of these ions in the absorbing solution will change its conductivity and an electrical signal proportional to the amount of SO_2 absorbed will be measured. The instruments using deionized water as an absorber convert the SO_2 to sulfurous acid which is a weak conductor. The conductivity of sulfurous acid is enough to operate a conductivity cell but not strong enough to be distinguished from the carbonic acid, a weak acid, formed by CO_2 absorbed from the ambient air. For this reason the SO_2 must periodically be scrubbed from the incoming air in order to obtain a background reading for comparison. This disadvantage must be weighed against the fact that the deionized water SO_2 monitors will operate for extended periods of time unattended, while the hydrogen peroxide monitors require frequent replenishment of the hydrogen peroxide. However, both types of instruments are susceptible to interferences and erroneous readings caused by other gases such as H_2S and NH_3 which will dissolve in the absorbing reagent. For this reason conductimetric measurement of SO_2 in ambient air has largely been superceded by more specific methods.

1.2 COLORIMETRIC

Colorimetric ambient air SO_2 monitors are usually an automated version of the pararosaniline method (usually by the West-Gaeke method) for determining SO_2 in ambient air. Although the latter method is quite acceptable when performed manually in the laboratory, the automation of it is cumbersome. In particular it requires sequential coupling of an air bubbler, reagent addition and color development delay tube, and a colorimeter. Instruments operating on this principle have as yet to demonstrate a satisfactory degree of reliability. Additionally, considerable quantities of waste reagent containing a toxic mercury salt are generated. For these reasons colorimetric monitors for SO_2 in ambient air have largely been replaced by other methods.

1.3 COULOMETRIC

The two most commonly used coulometric monitors for SO_2 in ambient air operate as follows. The sample is bubbled through a solution of either iodine/potassiumiodide or bromine/potassium bromide with the SO_2 being oxidized to sulfuric acid by the free iodine or bromine. At the sample cell anode the current is regulated to generate a constant concentration of iodine or bromine. As SO_2 reacts with the free halogen, additional current is required to maintain the original halogen concentration. This current is dependent upon the concentration of SO_2 in the ambient air. The measured magnitude of the current is converted to an output signal which is directly proportional to the SO_2 concentration in the ambient air. These instruments have a good reputation for reliability and only require maintenance on a weekly to quarterly basis, depending on the make.

1.4 PERMEABLE MEMBRANE - ELECTROCHEMICAL TRANSDUCER ANALYZER

These SO_2 monitors operate on a principle of first diffusing the SO_2 through a selective semi-permeable membrane and then oxidizing it at an electrode surrounded by solid electrolyte. The manufacturers of this type of monitor treat the details of the membrane and electrode construction as proprietary information; therefore, a detailed description of the mode of operation is not presently available. However, their instruments have a record of successful operation in the field over the past several years. The membrane electrode sensor is packaged separately from its signal conditioning amplifier and is replaced on exhaustion. This is generally necessary at three to six month intervals, depending on the SO_2 concentration being measured. One special characteristic of these sensors is that they will not withstand a negative pressure; therefore, the sample must be supplied to them by a positive pressure pumping system. The manufacturers of this type of sensor make "Teflon" lined pumping and sampling systems which meet this requirement without degrading the sample.

1.5 FLAME PHOTOMETRIC AND GAS CHROMATOGRAPHIC FLAME PHOTOMETRIC

The principle of operation of the flame photometric SO_2 monitor is to combust a sample of ambient air in an atmosphere of hydrogen. Any sulfur compounds present have the sulfur reduced to an excited atomic state by the hydrogen atmosphere. The excited sulfur very rapidly decays to the normal state and emits a photon of ultraviolet light. An optical system focuses the flame area through an ultraviolet transparent filter onto a phototube. The emitted ultraviolet light causes the phototube to produce an electrical output which is logarithmically proportional to the amount of sulfur in the ambient air. All sulfur containing gases, not just SO_2, give a response. If only SO_2 is expected to be encountered in the ambient air, the flame photometric sensor is satisfactory by itself; if other sulfur containing gases are expected, it is necessary to couple the flame photometric detector to a gas chromatograph which is capable of separating the different sulfur compounds. Several manufacturers market such a combined instrument. The combined instrument will monitor not only SO_2, but also H_2S and the lower molecular weight mercaptans. This advantage is somewhat offset by the extra maintenance and calibration required for either option.

1.6 FLUORESCENCE

SO_2 fluorescent analyzers have been developed for monitoring SO_2 sources and recently at least one manufacturer has begun to offer ambient instruments which measure SO_2 by this technique.

SECTION 2

CALIBRATION PROCEDURES FOR AUTOMATED AMBIENT SO_2 ANALYZERS

2.0 ORIGIN

The material which follows is a slightly modified extract of chapter 8 of reference 4 - "A Guide for the Evaluation of Atmospheric Analyzers" by Dr. P. K. Mueller et al. If the entire document is desired, appropriate EPA regional office should be contacted, refering to EPA contract 68-02-0214 of June, 1973. This information will be valuable for review purposes should control agency personnel desire to observe or perform actual calibrations of the ambient SO_2 monitors in the source operator's SCS network.

2.1 PRINCIPLE AND SCOPE

2.1.1 This procedure is for the calibration of continuous atmospheric sulfur dioxide analyzers. The calibration may be of two types, dynamic and static. The dynamic calibration must always be done and is performed by determining the analyzer response to a series of sulfur dioxide (SO_2) concentrations. The dynamic calibration is a performance test of the entire analyzer under simulated service conditions and is applicable to all SO_2 analyzers. The static calibration is performed by determining the analyzer response to artificial stimuli such as standard calibrating solutions, optical filters, screens, electrical signals, resistors, etc. This calibration is a test of the detection and signal presentation components only and is primarily applicable to SO_2 analyzers using wet-chemistry such as colorimetry and conductimetry. It is not a substitute for the dynamic calibration.

2.1.2 The calibrating gas for the dynamic calibration may be generated in two ways. The preferred method is by mixing a stream of

SO_2 from an SO_2 permeation apparatus[1,2,3] (Figure 2-1) with clean air. Alternatively, streams of dilute SO_2 (50 to 100 ppm; 131 to 262 mg/m^3) from a cylinder may be mixed with clean air.

The calibrating gas is sampled simultaneously with the analyzer and with the referee method[4] to establish the concentration of the gas. A permeation tube with a known emission rate can be used as a primary standard (see 2.6.1) source of SO_2 gas.

2.1.3 The static calibration is performed by adding known concentrations of a standard reagent to measured volumes of the analyzer absorbing solution which provide an effect equivalent to concentrations of SO_2. These solutions are flowed through the analyzer detector at the actual reagent flow conditions encountered during normal operation. The analyzer readings are plotted versus equivalent SO_2 concentrations to obtain a static calibration curve. The instrument variables (e.g., air and liquid flow rates) may be adjusted to make the output response conform to the pollutant concentration or to a simple multiple or fraction of the concentration in parts per million (ppm) or micrograms per cubic meter (µg SO_2/m^3) (spanning). When a static calibration is not performed, the spanning may be done during dynamic calibration.

2.2 RANGE

The range of the calibration procedure is determined by that of the referee method[4]. For a 10-liter sample collected in 10 ml of absorbing solution and measured in a 1.0 inch cuvette, the range is between 0.01 to 10 ppm SO_2 (0.026 to 26 mg SO_2/m^3).

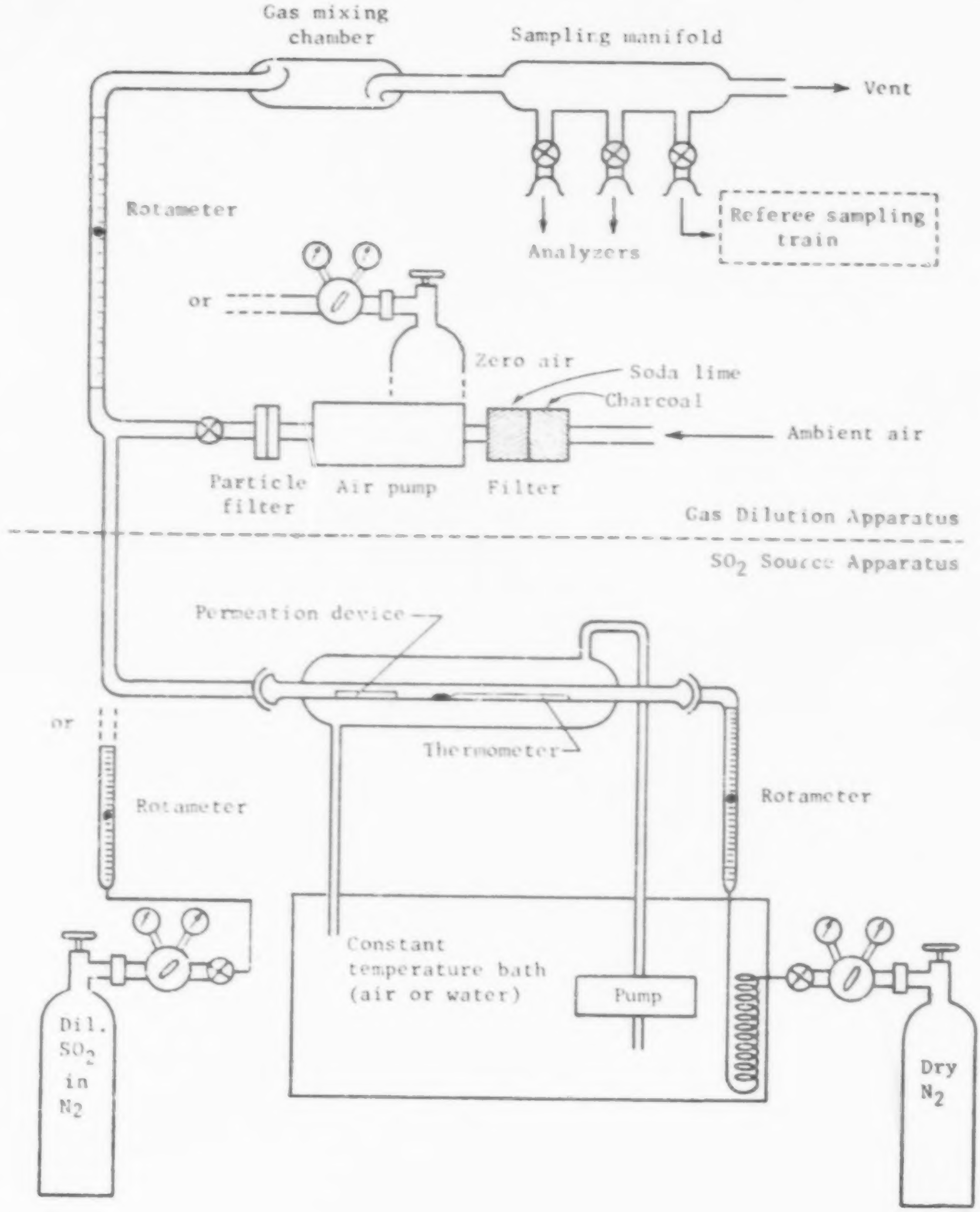

Gas mixing chamber
Sampling manifold
Vent
Rotameter
Analyzers
Referee sampling train
or
Zero air
Soda lime
Charcoal
Ambient air
Particle filter
Air pump
Filter
Gas Dilution Apparatus
SO_2 Source Apparatus
Permeation device
or
Thermometer
Rotameter
Rotameter
Constant temperature bath (air or water)
Pump
Dil. SO_2 in N_2
Dry N_2

Figure 2-1. Gas generating system for calibrating SO_2 analyzers.

The measurement range and the sampling rates of continuous SO_2 analyzers vary greatly depending on the detection methods. The upper limit of the measuring range can vary from 0.2 to 10 ppm (0.52 to 26 mg/m^3). Sampling rates may vary between 0.015 to 5 l/min. A descriptive compilation of most of the currently available SO_2 analyzers is given in Reference 5.

2.3 INTERFERENCES

2.3.1 Interferences are a function of the detection principle. SO_2 with purity greater than 99.9% is readily available; higher purities are obtainable when required. Zero air for dilution must be free of SO_2 and other substances that can potentially interfere in the analyzer detection principle. Selective absorbers (drying agents, Ascarite for CO_2, etc.) can be used whenever a particular measurement principle requires it.

2.4 PRECISION, ACCURACY, AND STABILITY

2.4.1 With careful work, the coefficient of variation at the 95% confidence level of the pararosaniline referee method is 4.6%[6]. Careful attention to the details of the method is critical.

2.4.2 When spanning is possible, any discrepancy between the input and output may be resolved by adjusting the instrument output to correspond to the calibrating gas concentration. Where analyzers have no spanning controls, a correction factor may be calculated to convert the analyzer readings to SO_2 concentrations.

2.4.3 A detailed discussion of the various sources of error in the preparation of calibrating gases is given in Reference 7, Part I: General Precautions and Techniques. The appreciation and minimization of the sources of errors are important to assure high levels of accuracy and precision.

2.5 APPARATUS

A gas generation system consisting of sources of SO_2 and zero air, flowmeters, gas mixing chamber, sampling manifold and a sampling train for referee analysis is needed in the dynamic calibration (Figure 2-1). The system should be capable of providing calibrating gases between 0.002 to 1.0 ppm (0.005 to 2.6 mg SO_2/m^3). The SO_2 may be furnished from an SO_2 permeation apparatus or from a cylinder of dilute SO_2 gas.

The components and connecting lines making up the system should be sized and assembled so that the differences in the gas pressure between the various components do not exceed 2% overall to prevent errors in flowrate measurements. Ball and socket joints are convenient for connections that are frequently made and broken.

2.5.1 SO_2 Permeation Apparatus: See Figure 2-1. This can also be purchased.

1. Flowmeters: To measure the flows of zero air (0 to 1 liter/min) over the permeation tube. They should be calibrated frequently (monthly) with wet or dry test meters, soap bubble meter or calibrated rotameter.

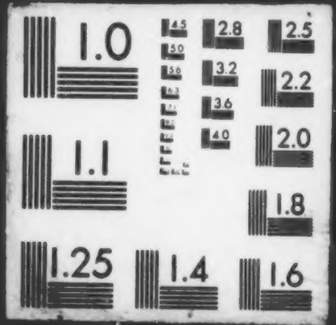
2. Temperature-controlled Bath: Maintained at 20 to 30 ±0.1°C. It is needed for proper operation of permeation tube 2.6.1. The baths described for SO_2[4,7] are acceptable.

3. Needle valves: for controlling the rate of gas flows. Stainless steel type is recommended for SO_2.

2 OF 2

PB

247 789


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

4. Thermometer: A laboratory type or other temperature-measuring device is needed to measure with a precision of 0.1°C or better the temperature of the constant-temperature bath and the zero air (carrier gas) flowing over the permeation tube.

2.5.2 Gas Dilution Apparatus (when cylinder SO_2 is used)

1. Flowmeters: To measure the rate of SO_2 and zero air flow. Calibrate frequently (at least monthly) as indicated in 2.5.1, Item 1.

2. Needle Valves: to control gas flow rates. Stainless steel types are recommended for SO_2.

3. Mixing Chamber: A cylindrical Kjeldahl type connecting bulb of 200 to 300 ml volume works well. This can also be fabricated from borosilicate glass as shown in Figure 2-1.

4. Sampling Manifold: Fabricate from borosilicate glass (see Figure 2-1). It should contain three or four ports to permit simultaneous sampling of the calibrating gas stream with the analyzer(s) and the referee method.

2.5.3 Zero Air Source

The zero air for diluting the calibrating gas should be free of SO_2 and substances that will in any way 1) change the calibrating gas concentrations, 2) interfere in the analyzer response and 3) interfere in the referee method. The zero air may be furnished from a cylinder or by filtering ambient air as indicated in Figure 2-1.

1. Air pump (for transport of ambient air) - A diaphragm or carbon vane pump capable of delivering flow rate requirements of the total generation system (5 to 10 liters/min) is needed. A particle filter should be installed on the downstream side of carbon vane pumps and is optional for diaphragm pumps.

2. Filters for Ambient Air: See 2.6.4.

2.5.4 Manual Sampling Train and Apparatus for Referee Analysis: See Reference 4 and Figure 2-2.

2.5.5 Analytical Balance: A laboratory type with a sensitivity of 10 μg or better is needed for weighing the permeation tube.

2.5.6 Calibrating Solution Dispenser (for static calibration): A solution dispenser, consisting of one or two lengths (about 50 cm) of small diameter (about 1.5 mm I.D.) clear polyvinylchloride (PVC) tubing, a plastic anti-syphon device and a 125 ml low-actinic separatory funnel as shown in Figure 2-3, is used to deliver the calibrating solutions under controlled flow conditions by means of furnished screw clamp(s) on the tubing(s). This (hypodermoclysis) set, which is intended for administering fluids under the skin, is inexpensive and can be purchased from medical supply houses. A similar device can be fabricated from small diameter plastic tubing, Y connector and screw clamps.

2.5.7 Apparatus for Static Calibration: refer to the manufacturer's instructions for a list of the required apparatus.

2.5.8 Absorber (Impingers): All-glass midget impingers are recommended for collecting the samples for referee analysis. See

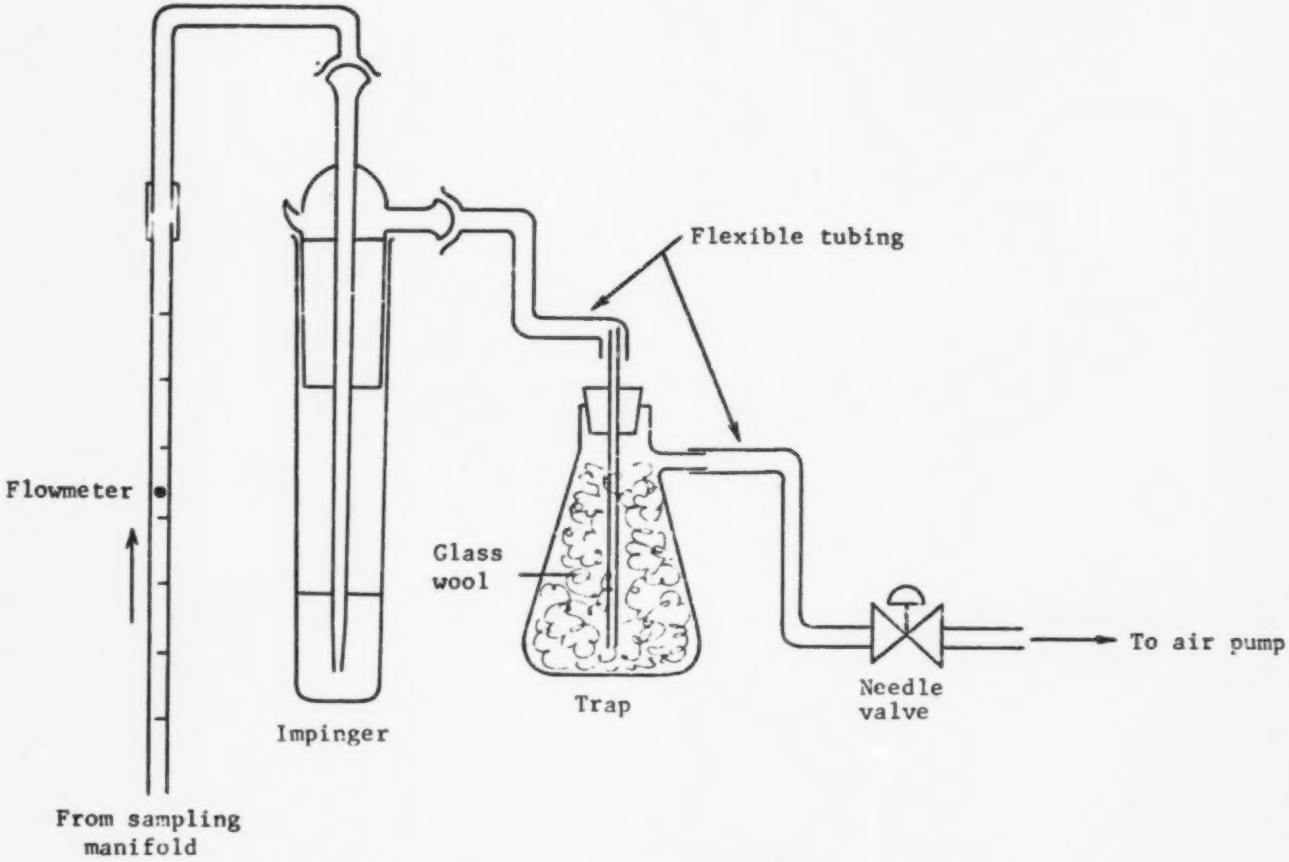

Flexible tubing
Flowmeter
Glass wool
From sampling manifold
Impinger
Trap
Needle valve
To air pump

Figure 2-2. Sampling train for referee SO_2 analysis.

Reference 4 for specifications. The impingers may be purchased from glassware suppliers. Two absorbers in series are needed to insure complete collection of the sample. Ball-joint connections are recommended for convenience.

2.6 REAGENTS AND GASES

Purity of chemicals - Unless otherwise specified, all reagent specifications shall conform to the committee on Analytical Reagents of the American Chemical Society[8]. When such reagents are not available, ascertain that they do not lessen the accuracy of the determination.

2.6.1 SO_2 Permeation Tubes: Permeation tubes containing SO_2 are commercially available in a variety of sizes and permeation (emission) rates[9,10]. The rates may be either nominal or certified. Certification can be done by the supplier at additional cost or by the user in his own laboratory. To assure maximum reliability, these tubes should be weighed regularly (e.g., at least once a month) and just before use. Certified tubes can also be obtained from the National Bureau of Standards.

2.6.2 Cylinder SO_2 (50-100 ppm; 131-262 mg/m^3): This gas mixture is further diluted to produce the desired concentrations for calibration. The concentrations produced should never be considered as primary standard and must always be standardized by the referee method or compared to the analyzer response obtained with a certified SO_2 permeation device.

2.6.3 Zero Air: A high-pressure cylinder of synthetic zero air, or filtered ambient air from an air pump may be used.

2.6.4 Zero Air Filter: Activated charcoal and soda lime used together will remove residual SO_2 and most interferents from the zero gas stream. Excessive amounts of nitric oxide in ambient air can be removed by placing a CrO_3 oxidizer before the soda lime.

2.6.5 Reagents for Referee Method for SO_2: see References 4 and 7.

2.6.6 Reagents for Static Calibration: refer to the manufacturer's operating instructions for a list of required reagents.

2.7 SPECTROPHOTOMETER CALIBRATION

1. Prepare a series of calibrating solutions containing the equivalent of 0.05 to 0.4 µl SO_2/ml (i.e., 1,2,3 ml) as described in the manual referee method[4]. Treat the solutions (Ref 4) and wait 30 minutes for full color development. Determine the absorbance of the solutions on the spectrophotometer against reagent blank.

2. Plot the net absorbance on the vertical axis versus µl SO_2/ml on the horizontal axis of a rectilinear graph paper as a check for linearity. Calculate the slope b of best-fit curve for the data using the method of least squares.

2.8 DYNAMIC CALIBRATION

2.8.1 General

1. When a static calibration (2.9) is to be performed on the analyzer, it should be done before the dynamic to assure proper operation of its detection and signal presentation components. The static and dynamic responses may be compared (reconciled) to verify the proper operation of

the analyzer and the validity of the calibration. See 2.10 for details.

2. When the analyzer has been operating as a continuous monitor, it is useful to determine its response near the span level first without changing the span settings (auditing). When the response is within ±10% of the previous calibration, the calibration is still valid and a new calibration is not necessary. When the response is greater than ±10% proceed with the complete calibration.

   The audit data provide a record of the calibration drift. Instruments with non-linear response require the full calibration.

3. The analyzer to be calibrated should be in good operating condition and installed in accordance with manufacturer's instructions. Operate the analyzer for at least 24 hr to warm-up. This 24-hr warm-up period may be shortened if so stated in the operating instructions. Adjust the air and reagent flowrates to their recommended rates or to the rates determined from the static calibration (2.9) data and verify the rates as described in 2.5.1, Item 1.

4. Record all data only after stable analyzer response has been attained.

5. Newly prepared SO_2 permeation tubes may be used after one day (24 hr) of equilibration at a constant temperature provided the concentrations produced are established by the referee method. A minimum of 30 days is required to establish that the emission rate is stable and before the emitted concentration can be used as a primary standard.[1]

The tube should be equilibrated for at least 12 and preferably 24 hours whenever the temperature is changed by more than ±5°C. See Reference 7 for general precautions pertaining to permeation tubes. It is generally desirable to precondition all SO_2 gas lines for ½ to 1 hour by flowing a stream of dilute SO_2 through them.

2.8.2 Procedure

1. Place the gas generation system as close as practical to the analyzer to prevent losses and to minimize pressure changes in the analyzer sampling duct. Calculate the airflow of the analyzer and add the airflow needed for the referee analysis (1.0 to 2.0 liter/min.). Add about 10% of the total to insure an excess. (NOTE: The excess calibrating gas should be vented to a hood or absorbed by a soda lime trap to avoid exposure to personnel.) In a proper assembly, connection or disconnection of the analyzer sampling line should not alter the airflow settings.

2. Generate a flow of zero air equal to the rate determined in Step 1 above. Pipet the required volume of absorbing reagent in the impinger (Item 2.5.8) according to the manual referee method[4]. Connect the impinger to the sampling train as shown in Figure 2-3. When a stable analyzer response is obtained, sample the gas stream from the manifold for 30 minutes at the rate directed in Reference 4. Transfer the exposed solution to a 25 ml volumetric flask. Develop the color of the solution in accordance with the referee procedure[4] and read the absorbance at 560 nm. When the absorbance of the solution is greater than the blank, continue flushing the gas generation system until the absorbance obtained is the same as the blank. Inability

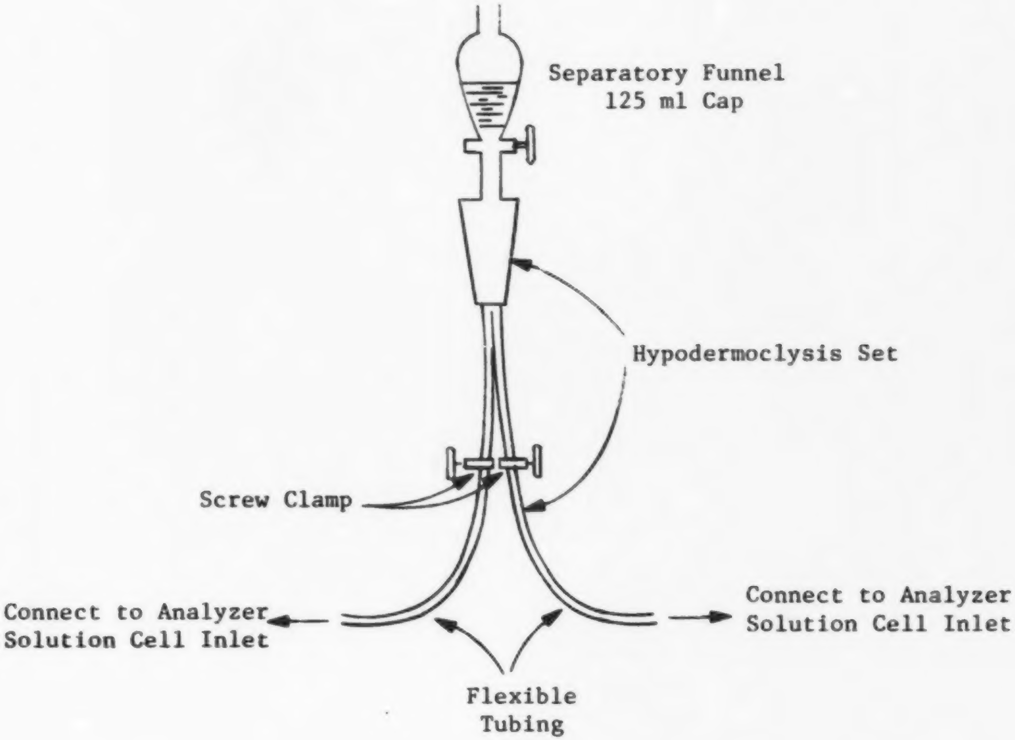

Separatory Funnel
125 ml Cap
Hypodermoclysis Set
Screw Clamp
Connect to Analyzer Solution Cell Inlet
Connect to Analyzer Solution Cell Inlet
Flexible Tubing

Figure 2-3. Calibrating solution dispenser

to obtain a reading equal to the blank indicates interferents in the zero air. Correct the source of the problem(s) before proceeding.

Zero the analyzer by adjusting the analyzer controls so that the output corresponds to zero or the desired reading.

3. Generate an SO_2 concentration equal to 80 ±5% (span gas) of the full scale reading (0.80 ppm for full scale of 1.0 ppm; 2.10 mg SO_2/m^3 for full scale of 2.62 mg/m^3). When the analyzer response is steady, record the analyzer reading.

4. When a permeation tube system is used and has been shown by frequent referee analysis to provide reliable SO_2 concentrations, the collection of referee samples may be omitted. The SO_2 concentrations are calculated from the diluent gas flow and permeation rates by equation 1 or 2.

   a) To determine the concentration of SO_2 in ppm (μl/l) from the permeation tube emission rate, use equation 1.

$$\text{ppm} = \frac{P}{2.62\ (Q_d)} \qquad (1)$$

   where P = permeation rate in μg/min.

   Q_d = rate of zero (diluent) air in liters/min.

   b) When the concentration units are desired in $\mu g\ SO_2/m^3$ instead of ppm, then:

$$\mu g\ SO_2/m^3 = \frac{(P \times 10^3)\ (\ell/m^3)}{(Q_d)} \qquad (2)$$

5. To establish the SO_2 concentration by referee analysis:

a) Collect duplicate samples of the gas stream and analyze as described in the referee method[4]. Adjust the sampling period to keep the absorbances of the samples at about midscale (0.3 to 0.5A) on the spectrophotometer. Five to 30 minutes are usually sufficient. For maximum precision, place the flasks containing the reacted solutions in a bath maintained within 2°C of the temperature used during the development of the spectrophotometer calibrating solutions.

b) From the volume of air sampled and the slope of the spectrophotometer calibration curve, calculate the ppm SO_2 as directed in equation 3.

$$\text{ppm} = \frac{(A)\ (25)}{(b)\ (V_a)} \qquad (3)$$

where: ppm = concentration ($\mu l/l$) SO_2

A = net absorbance of the solution

b = slope of the spectrophotometer calibration curve obtained in 2.7

V_a = volume, in liters, of the gas sample collected (liters/min X min)

To convert ppm to $\mu g/m^3$, use equation 4

$$\mu g\ SO_2/m^3 = \text{ppm}\ SO_2 \times 2620 \qquad (4)$$

Usually, changes in the gas volume of the samples due to deviation from the standard conditions of 25°C and 760 torr are small and may be neglected. When the deviations are large, (sufficient to cause a change in gas volume greater than about 5%) correction should be made.

c) The concentrations of the duplicate samples should be within 5%. Differences greater than 5% may be due to unstable gas concentrations, errors or inconsistencies in sample collection and analysis. Correct these problems before proceeding with the calibration.

6. When possible, adjust the analyzer to give reading equivalent to the span SO_2 concentration (spanning). When the instrument has no span controls, proceed to Step 7 below. Generate zero air and note the analyzer reading. When the reading is different from the original baseline reading by ≥2%, reset the analyzer to read the original baseline and repeat Steps 3 through 6 above. Analyzers with zero and span controls not electrically independent may have to be respanned and rezeroed iteratively until the proper zero and span settings are obtained.

7. Generate, in turn, four additional SO_2 concentrations between the blank and span range (e.g., 10, 20, 40, and 60% of full scale) and determine the SO_2 concentrations in duplicate and analyze as directed in Steps 3 through 5 above. Determine the net analyzer readings by subtracting the baseline reading from the individual readings.

2.8.3 Treatment of Dynamic Calibration Data

1. Plot the net analyzer readings on the vertical axis versus the corresponding SO_2 concentrations on the horizontal axis of an appropriate graph paper (rectilinear, semi-log,

log, etc.). Calculate the slope b_d of the best-fit curve for the data by the method of least squares. A non-linear response from an instrument normally linear indicates analyzer malfunction or, possibly, errors in the preparation of the calibrating gases. Correct the cause of the problem(s) before recalibrating.

2. When a non-linear response is normal, draw a smooth line through the calibration points that fits the points best. From this, prepare a template to convert the net analyzer readings to SO_2 concentrations.

2.9 STATIC CALIBRATION

The following section pertains to SO_2 analyzers using wet-chemical methods (colorimetry and conductimetry). See also 2.1.3.

2.9.1 Procedure

Prepare calibrating solutions (equivalent to 10, 20, 40, 60, and 80% of full scale) and perform the static calibration according to manufacturer's instructions. In the absence of such instructions the static calibration procedures described in Chapter 6 of this manual (Dr. Muellers Manual, SCS Ref. 4 of Vol. I) for automated oxidants and ozone analyzers, may be used as a guide.

2.9.2 Treatment of Static Calibration Data

1. Plot the net analyzer readings on an appropriate graph paper (rectilinear, semi-log, etc.) against the equivalent $\mu l\ SO_2/ml$ of the calibrating solutions. Calculate the slope b_s of curve that best fits the data by the method of

least squares. A non-linear response from an instrument normally linear indicates malfunction in the analyzer or error in the static calibration process. Correct problem(s) before recalibrating.

2. When a non-linear response is normal, prepare a template as directed in Step 2 of 2.8.3. An alternate method is to attempt to linearize the instument output by adjusting the electronics (i.e. photometer, etc.) until a linear output is found over the range of pollutant concentration of interest.

2.9.3 Determination of Airflow Rate

For instruments not equipped with adjustable upper limit or span controls or when the range of span adjust is insufficient, the slope of the static calibration can be used to establish the sample airflow rate that will make the analyzer output correspond to the pollutant concentration or a simple fraction or multiple f_s of the concentration range as follows:

$$Q_a = (Q_r) \frac{(f_s)}{(b_s)} \qquad (5)$$

where: b_s = slope of the static calibration curve obtained in 2.9.2

Q_a = analyzer airflow rate, ml/min.

[illegible] = analyzer reagent flow rate, ml/min

f_s = range factor (e.g., ½, 1.0, 2.0)

2.10 RECONCILING THE STATIC AND DYNAMIC CALIBRATIONS

The static calibration slope b_s (2.9.2) and the dynamic calibration slope b_d (2.8.3) are compared by equation 6:

$$R = \frac{|b_s - b_d|}{b_s} \times 100 \qquad (6)$$

Large values of R (≥10%) are indicative of a) error in the analyzer's air or reagent flowrate; b) leaks or malfunction in the analyzer; c) poor quality reagents; d) error in the static or dynamic calibration process; or e) change in the sample collection efficiency of the analyzer. Consult the analyzer operating instructions and/or manufacturer and correct the problem(s) before recalibrating.

2.11 REFERENCES

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11. National Bureau of Standards, Office of Standard Reference Materials, Washington, DC 20234.

SECTION 3

CONTINUOUS STACK GAS MONITORING

3.0 ORIGIN

The following material was extracted from a training course given by the Air Pollution Training Institute of the Environmental Protection Agency. If the entire document is desired, contact should be made to the Air Pollution Training Institute, National Environmental Research Center, Research Triangle Park. The document to request is Course 468 - Source Sampling and Analysis for Gaseous Pollutants. This section will be a valuable reference when the control agency finds it necessary to inspect and/or calibrate the emission monitoring instruments.

3.1 INTERFACES AND CONDITIONING

The interfacing of continuous analyzers and their sample conditioning requires even more attention than noncontinuous analyses because the former usually operate over long periods of time unattended. The long periods of unattended operation increase the chance that plugged filters or condensation in the sampling line may go unobserved until too late. If this does occur the information covered by the malfunction time will be irretrievably lost.

The simplest and most direct method of extracting the sample from the source is to insert a probe, with a filter tip, into a point in the source where the pollutant being measured is representative in concentration of the entire discharge. The probe and filter should be constructed of a material which will withstand the conditions within the source and at the same time not adsorb any of the pollutant being measured. An example for extracting SO_2 from a stack would be a stainless steel tube containing a "Pyrex" glass tube with a plug of "Pyrex" glass wool in the end of the probe. Outside of the stack the "Pyrex" lining would connect to a heat traced "Teflon" tube which would lead to the sample conditioner. The heat tracing should be adequate to keep the sample above its dew point.

The sample conditioner is usually best purchased from the maker of the continuous analyzer, as he best knows the requirements of his instrument. It also avoids a situation where one manufacturer could lay the blame for inadequate performance on the other manufacturer's equipment. However in the case of multipollutant sampling, it may be more convenient to purchase a probe sampling line and manifold separately. The various instruments would then tap into the manifold. In this case assurances should be obtained from the various analyzer manufacturers that their equipment will operate satisfactorily from such a sample extraction system.

An alternate method of sample extraction has been proposed by C. E. Rodes in the Oct. 1973 issue of Instrumentation Technology. This method dilutes the sample with dry air near the probe inlet, and also injects calibration gas near the same point. If a dilution factor of 10 to 1 or more is acceptable to the analyzer, this method of sample extraction obviates most of the problems of sample conditioning. The method does require accurate control of sample and dilution air flow rates.

3.2 TYPES OF EXTRACTIVE MONITORS FOR SO_2, H_2S, NO_x, AND CO

3.2.1 Electrometric

The Dynasciences Corporation Division of the Whittaker Corporation* markets SO_2, NO_x, NO_2 and aldehyde analyzers which operate on a permeable membrane, coulometric measurement system. A wide range of sensors are available which will cover the concentrations of pollutants found in source stacks and in ambient air. They also manufacture sample extraction and conditioning systems designed for operation with their monitors. The sensing elements of the monitors have an expected life of 3 to 6 months and then must be replaced. The expended sensors can be recharged only by the manufacturer.

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*Trade names mentioned in this document are for the convenience of the reader and do not imply endorsement by the U.S. Environmental Protection Agency

International Biophysics Corp. of Irvine, Calif. manufactures a series of sensors for SO_2, H_2S, NO, NO_2 and NO_x. These sensors operate by polarographically sensing the pollutant which diffuses through a membrane. The polarographic sensor and membrane are contained in a special cartridge which plugs into the amplifier-signal conditioning unit. The response time on the system is quite fast, in the order of seconds, and recovery time equally so. International Biophysics Corp. manufactures complete sample extraction and conditioning units which are designed for compatability with their sensors. An example of an International Biophysics Corp. "EcoStation" for measuring a single pollutant is shown in Figure 3-1. The sample chilling unit is continuously blown down and the unit is stated to maintain sample gas integrity within 2%. International Biophysics Corp. sensors are made in ranges which cover both stack and ambient pollutant monitoring. The sensors again have a life of 3 to 6 months, after which a new sensor must be plugged into the signal conditioning unit and the sensor sent back to the manufacturer for recharging.

The Phillips Electronic Instruments division of Phillips of Holland markets coulometric analyzers for the measurement of SO_2, NO, NO_2, CO and H_2S. With the exception of the CO monitor, they operate on the principle of chemically reducing a HBr solution with the lost HBr being electrolytically regenerated. The current for the electroregeneration is measured which in turn gives a measurement of the pollutant. In the case of CO, I_2O_5 is reduced by the CO and the liberated I_2 is absorbed and measured coulometrically. These instruments were designed primarily for ambient monitoring, and in the case of high pollutant levels, sample extraction and conditioning by the air dilution method mentioned on page 2 would be necessary. They do offer the advantage of operating up to 3 months unattended

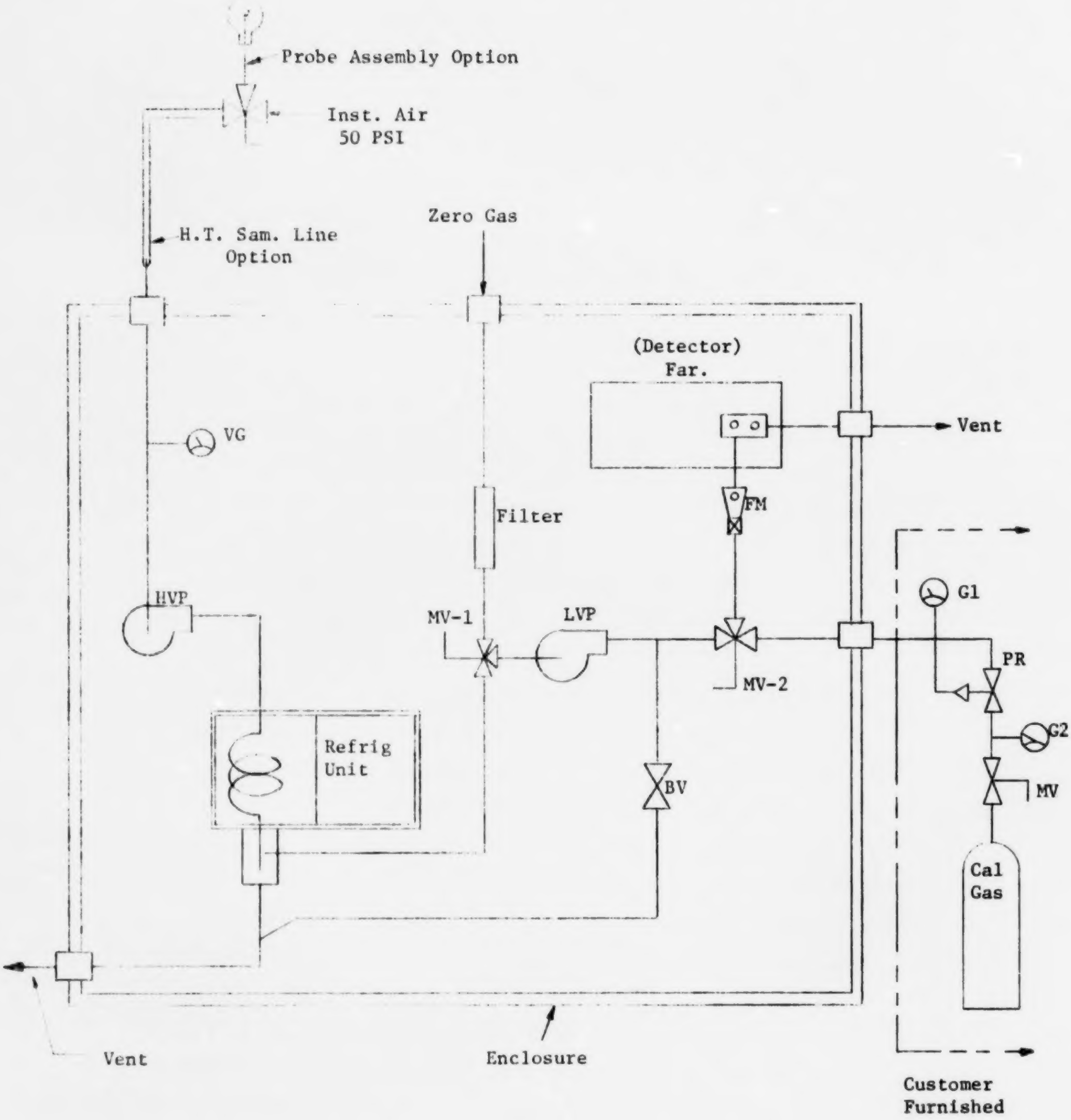
Probe Assembly Option
Inst. Air
50 PSI
H.T. Sam. Line Option
Zero Gas
(Detector)
Far.
Vent
VG
Filter
FM
G1
HVP
MV-1
LVP
MV-2
PR
G2
Refrig Unit
BV
MV
Cal Gas
Vent
Enclosure
Customer Furnished

Figure 3-1. "EcoStation" for Measuring a Single Pollutant (International Biophysics Corporation)

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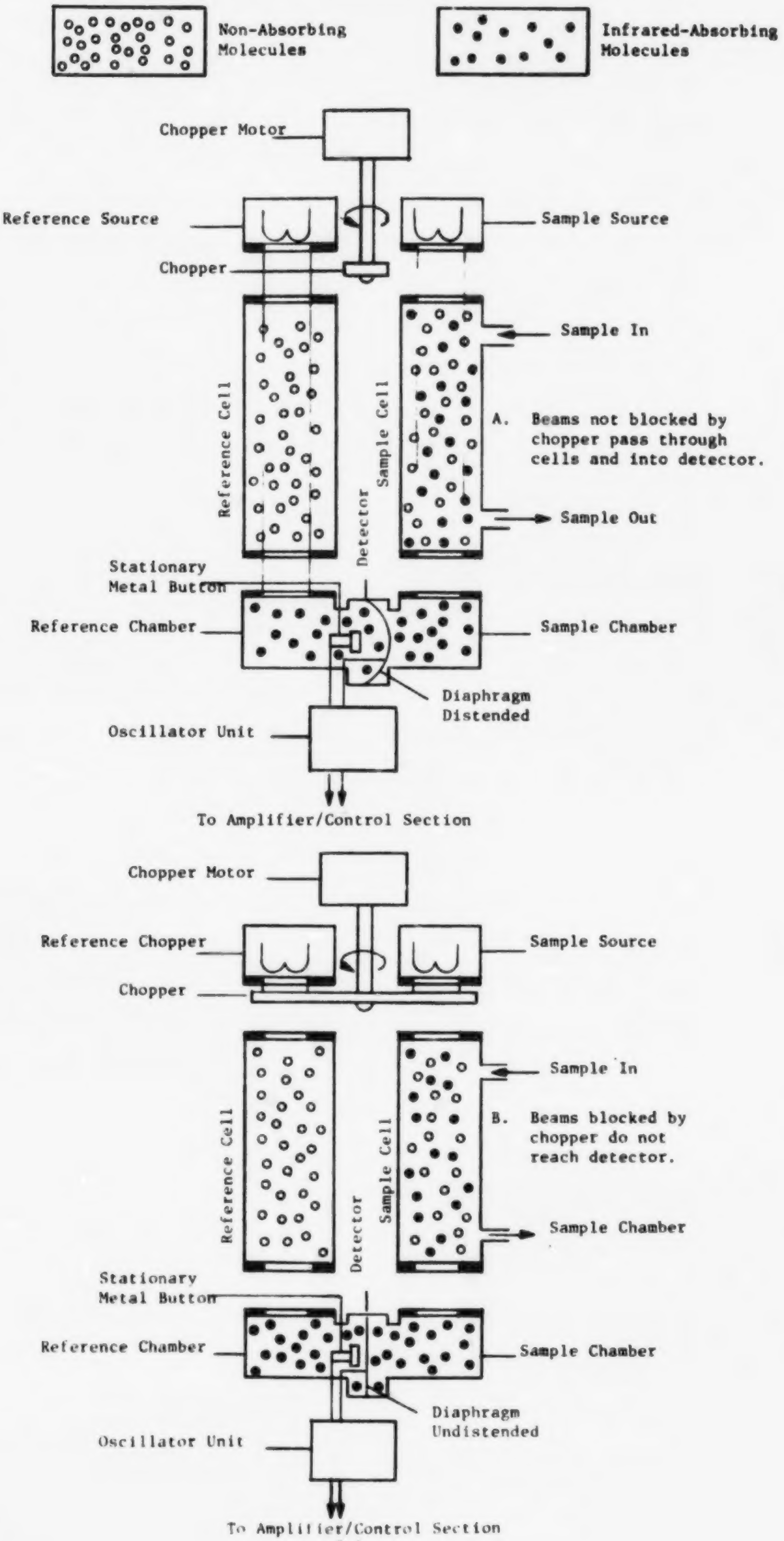
as they contain their own calibration source and have automatic zero and span adjustment.

Theta Sensors, Inc. markets a series of SO_2, H_2S, NO_2, NO and NO_x sensors which operate on the permeable membrane potentiometric principle. The individual sensing units are contained in a signal conditionong panel and will require replacement after 3 to 6 months. The sensor units must be recharged by the manufacturer. Theta Sensors, Inc. also manufactures sample extraction and conditioning units which are designed for operation with their sensors.

3.2.2 Spectrometric Monitors

Nondispersive infrared SO_2 and CO monitors are manufactured by Beckman Instruments, Leeds and Northrup and Mine Safety Appliance Co. Bendix Instrument Division imports one manufactured in Germany. They all operate on a very similar principle. Figure 3-2 illustrates the optical and detection system of a Beckman nondispersive analyzer, which is typical of this method of measurement. It consists of dual infrared sources and dual optical absorption cells. One of the latter is filled with a nonabsorbing gas while the other has the sample passed through it. A gas microphone, filled with the pollutant of interest, is placed at the end of the dual optical paths. A chopper (rotating occluder) alternately blocks and passes the infrared radiation through the optical system. If the sample cell contains the same gas as is confined in the gas microphone, less of the infrared radiation which is absorbed by the gas in the sample cell will reach the microphone cell on the sample side. The gas in the sample side microphone cell will then receive less infrared radiation which it is capable of absorbing, and will be heated less than the gas in

Figure 3-2. Optical and Detection System of Nondispersive Analyzer


Non-Absorbing Molecules
Infrared-Absorbing Molecules
Chopper Motor
Reference Source
Sample Source
Chopper
Sample In
Reference Cell
Sample Cell
A. Beams not blocked by chopper pass through cells and into detector.
Detector
Sample Out
Stationary Metal Button
Reference Chamber
Sample Chamber
Diaphragm Distended
Oscillator Unit
To Amplifier/Control Section
Chopper Motor
Reference Chopper
Sample Source
Chopper
Sample In
Reference Cell
Sample Cell
B. Beams blocked by chopper do not reach detector.
Detector
Sample Chamber
Stationary Metal Button
Reference Chamber
Sample Chamber
Diaphragm Undistended
Oscillator Unit
To Amplifier/Control Section

the reference side microphone cell. As the chopper causes the infrared radiation to be pulsed, this will cause a pulsing expansion of the gas on the reference side of the microphone causing the microphone diaphragm to oscillate. The oscillation will be proportional to the absorbing gas in the sample cell and is detected electronically.

With appropriate optical filters and gas filling of the microphone, the instrument may be made specific in response to SO_2, NO, NO_2, hydrocarbons and CO. However the weakness of non-dispersive infrared analyzers in source sampling is the degradation of the optics and internal optical coatings due to the corrosion from SO_2 and NO_2. Past experience has indicated that their performance may fall off in a period as short as a few weeks if the gas being monitored is corrosive. On the other hand they are one of the few instruments which will monitor CO at low levels (down to a few ppm).

Du Pont manufactures a visible-ultraviolet spectrophotometer which measures both SO_2 and NO_2 continuously and NO at 10 minute intervals. The optics of this spectrophotometer are much less susceptible to corrosive degradation than the non-dispersive infrared spectrophotometers as the sample tube is not internally coated with reflective material. However an interfacing system must still be employed to prevent particulate from entering the instrument, and the dew point of the sample must be lowered to ambient to prevent condensation in the spectrophotometer. The operating principle of the Du Pont Model 400 spectrophotometer is illustrated in Figure 3-3. As is shown in the plots in the lower half of Figure 3-3, SO_2 and NO_2 have well separated absorption peaks in the ultraviolet and visible portions of the spectrum. SO_2 has no absorption and NO_2 relatively little absorption in the orange part of

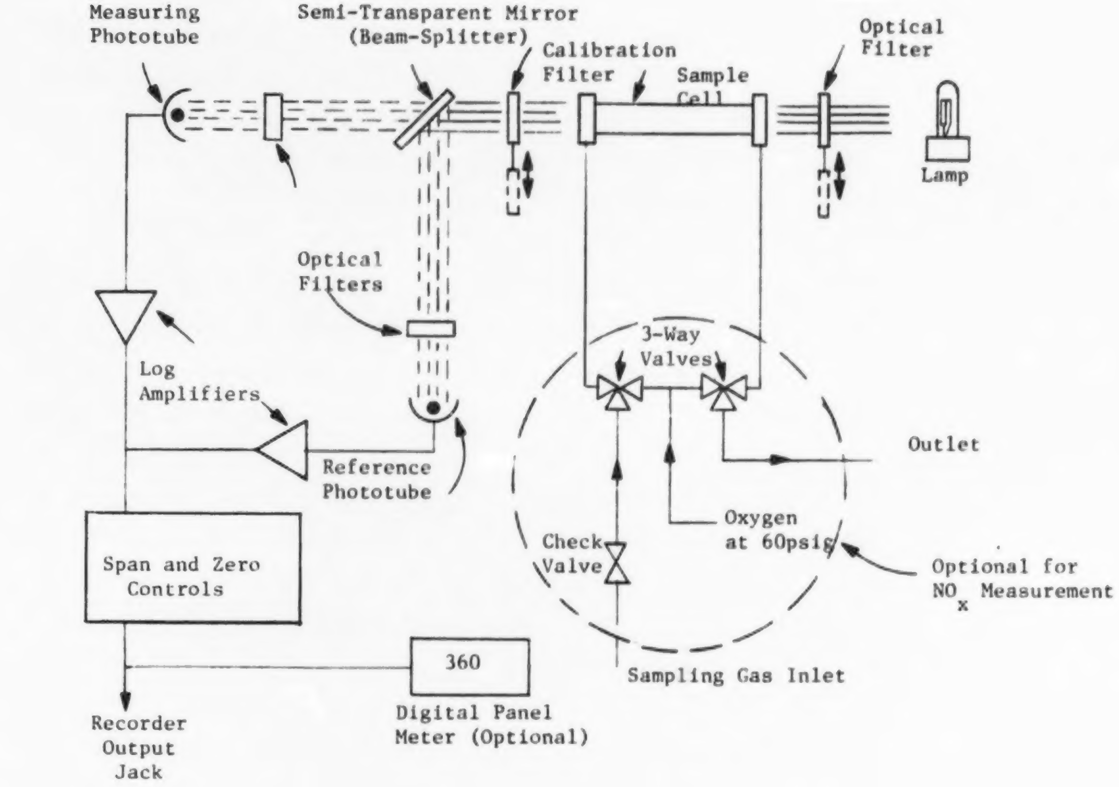
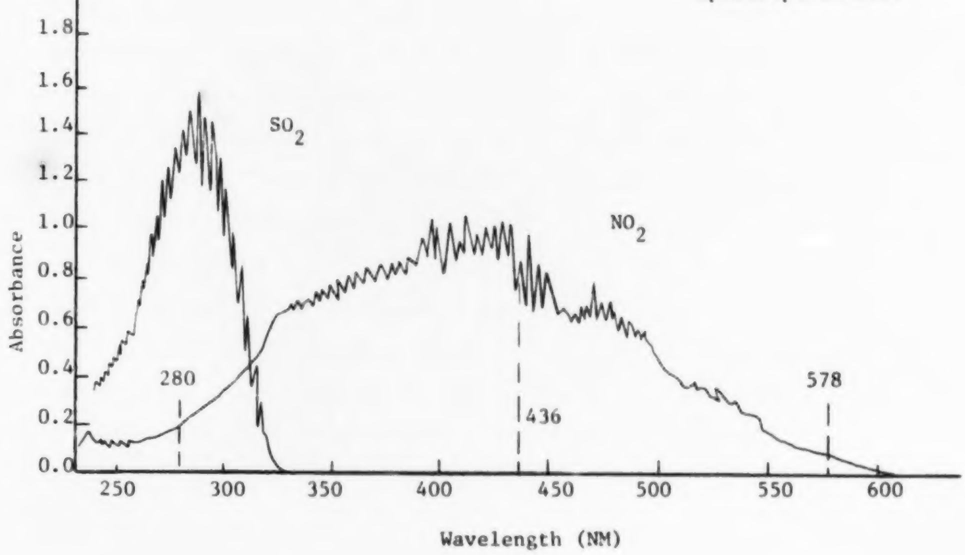

Measuring Phototube
Semi-Transparent Mirror (Beam-Splitter)
Calibration Filter
Sample Cell
Optical Filter
Lamp
Optical Filters
Log Amplifiers
Reference Phototube
3-Way Valves
Outlet
Oxygen at 60psig
Optional for NO_x Measurement
Check Valve
Span and Zero Controls
360
Digital Panel Meter (Optional)
Sampling Gas Inlet
Recorder Output Jack

Figure 3.3. Operating Principle and Typical Output of a DuPont Spectrophotometer



the spectrum. By using a mercury vapor lamp to generate light which has strong emission lines at the three wavelengths shown on the plot, the two pollutants can be measured by their selective absorption. NO has no absorption in this spectral region, but is measured by stopping the flow in the NO_2 sample cell, pressurizing it with O_2 and waiting ten minutes for the NO to be converted to NO_2 by the excess oxygen. The NO is then measured by the difference in the readings before and after the reaction with oxygen.

The upper half of Figure 3-3 illustrates the operating principle of the Du Pont Spectrophotometer. Light from a mercury vapor lamp is directed down the sample cell. A semi-transparent mirror passes half the light to the measurement phototube and at the same time deflects half to the reference phototube. Narrow bandpass filters pass the 280 nanometer mercury line (in the case of SO_2) or the 436 nanometer line (in the case of NO_2) to the measuring phototube. The reflected beam passes through a 578 nanometer filter to the reference phototube. By comparing the outputs of the phototubes, the amount of light absorbed by the SO_2 or NO_2 is measured. As the absorption of the light by the pollutants follows Beer's Law, logarithmic amplifiers convert the phototube output signal into a linear measurement of the specific pollutant.

The Du Pont spectrophotometric analyzer uses an air aspirator rather than a pump to draw the sample into the system. Therefore, a source of compressed air must be available for use with this analyzer.

Lear Siegler, Inc. manufactures NO_2 and SO_2 spectrophotometric flue gas analyzers which operate on a more elaborate principle. Rather than measuring peaks in the absorption spectrum of the stack gas the instrument responds to the second derivative of the absorption peaks. By choosing a sharp peak in the second derivative spectrum and scanning a narrow band of it (necessary to generate the second derivative) the sensitivity and specificity of the analyzer is stated to be much improved over that of the direct absorption spectrophotometric analyzers.

3.2.3 Fluorescence Spectrophotometers

Celesco Industries, Inc. manufactures an SO_2 monitor which operates on the principle of continuously irradiating an aspirated sample of stack gas with short wavelength ultraviolet light. The SO_2 then fluoresces at a higher wavelength in the ultraviolet. A narrow band pass filter passes the light created by fluorescence to a photomultiplier tube which measures its intensity. In the lower range of SO_2 concentration (0-500 ppm) the response is linear. Above 500 ppm the high concentration of SO_2 reabsorbs some of the fluorescent light, and the response becomes logarithmic rather than linear. Therefore, the instrument has two scales, a linear one for 0-500 ppm SO_2 and a logarithmic one for 0-5000 ppm concentration of SO_2. The instrument contains two calibration cells filled with sufficient SO_2 to span the monitor. This is accomplished by moving a calibration cell into the optical path in place of the sample cell. Both the high and low scales are spanned between 50% of full scale and full scale. As convenient as this feature is, it is not a dynamic calibration and the monitor should still be checked with external span and zero gases at intervals closely enough spaced to insure that it is reading the true value for SO_2.

The Thermo Electron Corporation makes a pulsed fluorescent SO_2 analyzer. This instrument also operates by irradiating the stack gas in a sample cell with short wavelength ultraviolet light and measuring the fluorescent light produced by SO_2 at a longer wavelength. However, the irradiating ultraviolet light is supplied by a flash tube which delivers the light in short pulses. The instrument is stated to be linear in response from 1 to 5000 ppm. Exactly how reabsorption of the fluorescent light is avoided is not spelled out in their literature, but a graph is provided by the manufacturer which indicates that the instrument reading versus SO_2 concentration is linear over a range of 0 to 2500 ppm. Also the life of the pulsating ultraviolet source is considerably longer than a continuously operating one. The monitor must be zeroed and spanned by calibration gases in the usual manner.

3.3 IN SITU MONITORING

3.3.1 Across the Stack Monitoring

The Environmental Data Corporation makes across the stack monitors for NO, SO_2, CO and CO_2. Polychromatic light is directed across the stack to the sensor which is mounted on the opposite side of the stack. The band of light absorbed by the pollutant of interest is passed alternately through a narrow band pass filter or directed straight to a reference detector. The same detector measures the light passed alternately by the filter and that sent directly to the detector and the two signals are compared. As the unfiltered light is affected by smoke and particulate as much as the filtered light, the effect of the changing opacity of the stack gas is largely cancelled out. This method avoids the problems of sample extraction and conditioning, but as might be expected from its simpler optical system, adjustments must be made for other absorbing gases. Calibration cells are automatically inserted into the instrument at predetermined intervals to calibrate it. However, this is not a dynamic calibration, and a dynamic calibration would be very difficult to perform on this instrument. However, a slightly less precise measurement in the sense of actually determining the pollutant in a given sample must be considered against the fact that the instrument measures across the entire diameter of the stack and avoids sampling problems.

CEA Instruments manufactures an in-stack monitor which senses SO_2 in a particular portion of the stack. The method of measurement is correlation spectrophotometry which is quite specific for SO_2. It works as follows: a beam of polychromatic light is directed down a probe placed in the stack and reflected back to the instrument by a mirror. A grating generates the spectrum of the light which has passed through the stack gas. A mask, which corresponds to the SO_2 absorption spectrum is oscillated across the light beam from the grating, alternately passing the SO_2 absorption spectrum and background light. The output from a detector is measured with phase reference to the mask position. This generates two signals, one corresponding to SO_2 absorption and one to background light. As both signals are equally affected by stack opacity, the resulting comparison of the two signals is a measurement of the SO_2 in the stack. As the instrument is mounted on only one side of the stack, it may be removed and calibrated. Although it does perform the analysis in the stack and without sample conditioning it monitors only a relatively small area of the stack and therefore must be located at a spot where the SO_2 concentration is representative of the entire stack.

3.3.2 Remote Sensing

Although work is in progress to use laser excitation and Raman back scattering for remote plume sensing, no proven instrumentation using this method is presently available. However correlation spectroscopy, mentioned in the previous paragraph, has been successfully used to accomplish this task. The difference in application is that no source of light is provided but the natural backlighting is used instead. Both SO_2 and NO_2 have been monitored in stack plumes by Environmental Measurements, Inc. using this method. It works as follows: an optical system focuses the area of interest on a mirror grating. The grating generates the absorption spectrum of the stack plume. An oscillating mask, cut to conform to either the absorption spectrum of SO_2 or NO_2, alternately passes the light of the absorption spectrum or the background light to a detector. The electronics following the detector are phased with the oscillating mask and generate two signals, one correlating to the absorption spectrum and one to the background light. The two signals are compared to obtain the total amount of pollutant "seen" by the spectrophotometer. The method is quite specific and can be calibrated by use of a sample cell filled with a known concentration of the pollutant being measured. The instrument, as manufactured by Barringer Research Ltd., has the additional advantage of easily being mounted in a mobile van. Its one disadvantage is that it requires background light to operate.

3.3.3 Methods of Calibration and Use of Referee Methods for Checking Performance

The extractive source pollution monitors are all calibrated in a similar manner. Span and zero gases are connected to a 3-way T in the sample conditioning train ahead of any chilling or conditioning equipment. The stopcock of the T is turned to pass the zero or span gas through the system and into the analyzer. In most cases the zero gas is passed first and when the analyzer has reached a steady reading it is zeroed according to the manufacturer's instructions. A span gas which will give approximately 80% of the full scale reading is then passed into the T and it is continued to be passed until the analyzer has reached a steady reading. The span of the instruments is then adjusted so that the analyzer reads the concentration of the pollutant in the span gas. Additional span gases should then be passed through the system which will cause the analyzer to read at 20%, 40% and 60% of full scale. Any deviation in the readings from the span gas composition should be noted, and used to plot a correction curve in analyzing the final data. Span gas may be supplied in cylinders with a certified analysis from the supplier. In the case of low levels of pollutants, and NO_2 in any case, permeation tubes in appropriate span gas generation systems are preferable to cylinder span gas. They are not quite as convenient, but at low levels of pollutant, and in the case of NO_2, give more certain results if the permeation tube conditioning and gas dilution equipment are properly operated.

In the case of the in situ monitors the calibration is more difficult, generally requiring removal of the monitor from the stack. Although it may require a special set up, these monitors should be periodically calibrated with zero and span gases as in the case of extractive monitors.

To ensure that all of the apparatus is working properly, stack gases should occasionally be analyzed in parallel with the instrumental monitoring using the referee methods given in the Federal Register or the expanded EPA publications for the same methods. If a time limited monitoring program is being performed, referee checks should be done at the start and end of the program, and at any time inaccurate results are suspected. If a chemistry laboratory is not available at the site to perform the referee methods a certified outside consulting laboratory should be called in to perform these checks.

3.4 DATA ACQUISITION

All of the continuous stack monitoring analyzers have analog electrical output signals. Some come with recorders attached to record these signals. A few even have digital output signals. If no recorder comes with the instrument this item may be purchased separately and connected to the analog output.

The final use of the data acquired will dictate whether a recorder tracing is sufficient or whether the data must be recorded in a form compatible with computer processing. If the latter is the case, an analog to digital converter must be interfaced between the monitor and a suitable tape recorder. The selection of this equipment is best left to the computer program manager, as he will know best what the requirements of the equipment are.

A computer program analysis of the stack monitoring data is most convenient when a varying concentration of pollutant is to be monitored over long periods of time. This is because intergrating many feet of chart paper by hand is a time consuming and tedious process.

SECTION 4

METEOROLOGICAL INSTRUMENTS

4.0 ORIGIN

The material which follows is excerpted from the 1975 Revision of the Air Pollution Training Institute, Course 435, Atmospheric Sampling, Chapter XXIII. This information should prove helpful as background material for greater understanding on the operational principles of many meteorological instruments. The control agency inspection personnel should use this section to become familiar with instruments which may be examined during an inspection or review. Paragraph and figure numbers from the original document have been retained in this section; only the page numbers have been changed.

XXIII. METEOROLOGICAL INSTRUMENTS

A. INTRODUCTION

Measurement of atmospheric variables that affect the diffusion and transport of air pollutants is necessary in nearly every air pollution investigation. Suitable measurements may be available from existing instrumentation at Weather Service city offices, airport stations, or from universities or industries with meteorological installations. Frequently, however, existing instrumentation does not give detailed enough measurements; is not representative of the area in question; or does not measure the variables desired (such as turbulence), so additional instruments must be operated.

Of primary importance in air pollution meteorology is the measurement of wind velocity (direction and speed) and the turbulence of the wind. The stability of the lower layers of the atmosphere in which the pollution diffuses is important and may be determined from an analysis of the turbulence characteristics of the atmosphere or the temperature lapse rate.

Of secondary importance is the measurement of humidity (which may affect atmospheric reactions), temperature, precipitation (of importance in washout of pollutants), and solar radiation (which affects photochemical reactions in the atmosphere). Particularly for research studies, it may be desirable to measure meteorological elements affected by pollutants, such as visibility, solar radiation, and illumination (radiation in the visible region).

B. WIND MEASUREMENTS

Surface Instrumentation for Measuring Wind Speed

Generally, wind speed sensors are broken down into the following categories:

- Rotational Anemometers:
  1. Vertical Shaft
  2. Horizontal Shaft
- Pressure Anemometers
  1. Flat Plate Type Anemometer
  2. Tube Type Anemometer
- Bridled Cup Anemometer
- Special Types
  1. Hot Wire Anemometer
  2. Sonic Anemometer
  3. Bivane
  4. UVW Anemometer

Pressure anemometers, hot wire and sonic anemometers have enjoyed extensive use in research type operations, but they all have disadvantages which have prohibited their use in operational type situations such as air pollution surveys. The rotational type anemometers are the most common type of wind speed sensor in use today mainly because they are the only types that satisfy all of the following desirable operational features:

1. Essentially linear relationship between the sensor output and the wind speed.
2. Calibration is unaffected by changes in the temperature, pressure or humidity of the atmosphere.
3. Able to measure a wind range of wind speeds (< 2 to 200 mph [.9 to 90 m/s]) .
4. Long term calibration stability. The calibration often is unchanged after 10 years continuous operation.
5. Output of the sensor is easily adapted to remote indication.
6. Recording of the wind speed data is easily adaptable to either analog or digital form.

7. Generally require extremely little maintenance.

- Vertical Shaft Rotational Anemometers

A cup anemometer revolving about a vertical shaft is probably the most frequently used anemometer. The most common of the cup anemometers are the 3-cup types shown in Figure XXIII-1.

Traditionally, anemometers have only had to yield average wind speeds for use in the support of aviation and weather forecasting operations. Sensors often were developed with durability as the primary requirement. These cups are about 10 cm. in diameter, with a moment arm of about 42 cm. These anemometers, due to their large mass, have a relatively high starting speed (that wind speed at which the cups first begin to rotate or reach the manufacturers accuracy specifications) of about 3 mph (1.4 m/sec). This factor of high mass combined with a long moment arm will also produce a high moment of inertia which tends to cause the cups to indicate erroneous wind speeds under gusty conditions. Not only will the instantaneous readings be in error, but because the cups accelerate faster than they decelerate, the mean speed indicated may be slightly higher than the true speed.

With the advent of environmental concern, an anemometer was needed that would measure light winds, which are of great importance in air pollution meteorology. Also, to support turbulence and diffusion studies, an anemometer was needed that would approach giving an instantaneous response to wind speed fluctuations. Lighter weight anemometers were developed for such purposes. To provide accuracy at low speeds and greater sensitivity, these small 3-cup anemometers are lightweight in construction (plastic or very thin aluminum) and employ a relatively short moment arm. In addition, friction has been reduced by utilizing miniature ball bearings and special type transmitters. The cups are generally 5 cm. in diameter and have a moment arm of about 7 cm. The result of these design considerations is more accurate instantaneous and average windspeeds.

The cup wheel has been redesigned in an attempt at further

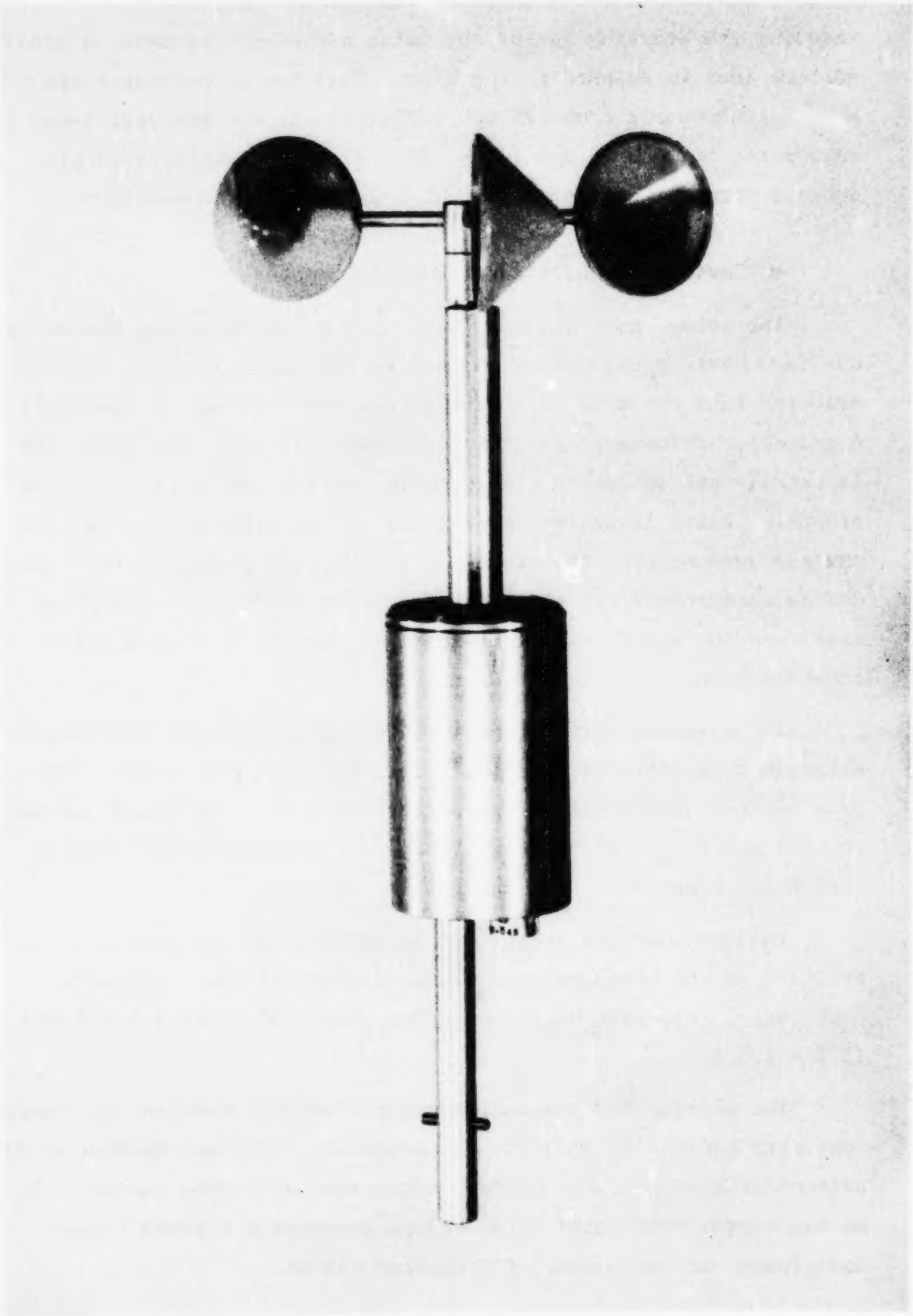


Figure XXIII-1: 3-CUP ANEMOMETRIC (COURTESY CLIMET INSTRUMENTS)

reducing the starting speed: by using six staggered cups, a greater surface area is exposed to the wind. This factor decreases the starting threshold from .75 mph (.35 m/s) for the standard 3-cup anemometer to .4 - .5 mph (.2 - .25 m/s). This design also produces a more uniform torque around the entire shaft revolution.

- Horizontal Shaft Rotational Anemometers

The second most commonly used wind speed measuring system is one that has a propeller on the end of a horizontal shaft that is oriented into the wind by a vane on the opposite end of the shaft. A propeller anemometer is shown in Figure XXIII-2. The propeller is usually helicoidal in design, with the rate of rotation of the propeller being linearly proportional to the wind speed. As with the cup anemometers, the propeller anemometers generally fall into two design categories: 1) those designed with durability as a prime consideration and 2) those designed with sensitivity as a prime consideration.

The more sensitive propeller anemometers utilize lightweight aluminum or plastic as blade material, and generally employ either 2 or 4 blades. The 2-bladed propellers have starting speeds of about .4 - .7 mph (.2 - .35 m/s), while the 4-bladed propellers have a threshold of about .3 - .5 mph (.15 - .25 m/s).

The more durable propeller anemometers use heavy gauge plastic or steel in the blade construction. Because of the relatively heavy mass, they have higher starting speeds of about 2.5 - 3 mph (1.2 - 1.5 m/s).

The sensitivity argument developed earlier for the cup anemometers also applies to propeller anemometers. However, because of the helicoidal design of the blades, the number of blades has no effect on the torque uniformity. The design produces a uniform torque independent of the number of propeller blades.

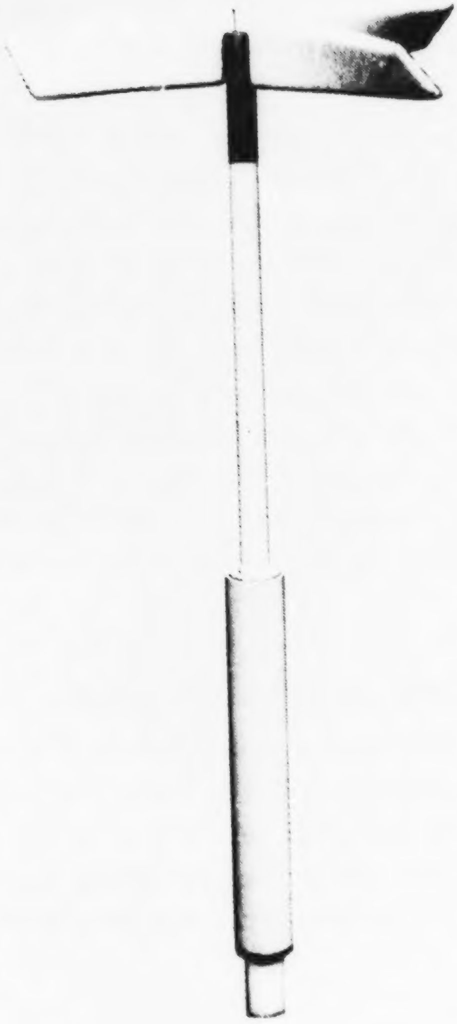


Figure XXIII-2: PROPELLER ANEMOMETER (COURTESY CLIMET INSTRUMENTS)

- Special Types of Anemometers

The propeller bivane anemometer is capable of measuring the magnitude of the wind vector and will be discussed more fully in the wind direction sensor portion of this section.

The UVW anemometer is another sensor configuration that yields the wind vector and its fluctuations is the UVW anemometer. Figure XXIII-3 shows one type manufactured by Climet Instruments. In this sensor configuration, a propeller anemometer is mounted in each principal axis (thus the name UVW), and each yields the component wind vector in that axial direction. This anemometer has found limited operational use because of the sophisticated data reduction that is necessary to convert from an output of three wind speeds to a vector magnitude and direction. The UVW anemometer has, however, enjoyed easy application to those situations where the three component vectors are the only desired output, or where data reduction is accomplished through the use of a computer. As with all sensors of the propeller type, serious error is introduced during periods of heavy precipitation, and with this particular propeller configuration there is some mutual interference error with certain wind directions.

Wind Speed Measuring Transducers

The most common aerodynamic sensor for the measurement of wind speed is the cup or propeller. The wind speed measuring transducer must convert this cup or propeller rotation to an energy form that is easily transmittable. The energy form is usually electric and the transducer is commonly one of the four types discussed subsequently.

- D.C. Generator

Small, permanent field D.C. generators are used that have an output which is linearly proportional to the rate of turning of the cup or propeller and, hence, is linearly proportional to the wind speed. The output from this transducer can be recorded directly on any D.C. galvanometer recorder. The main disadvantage of D.C.

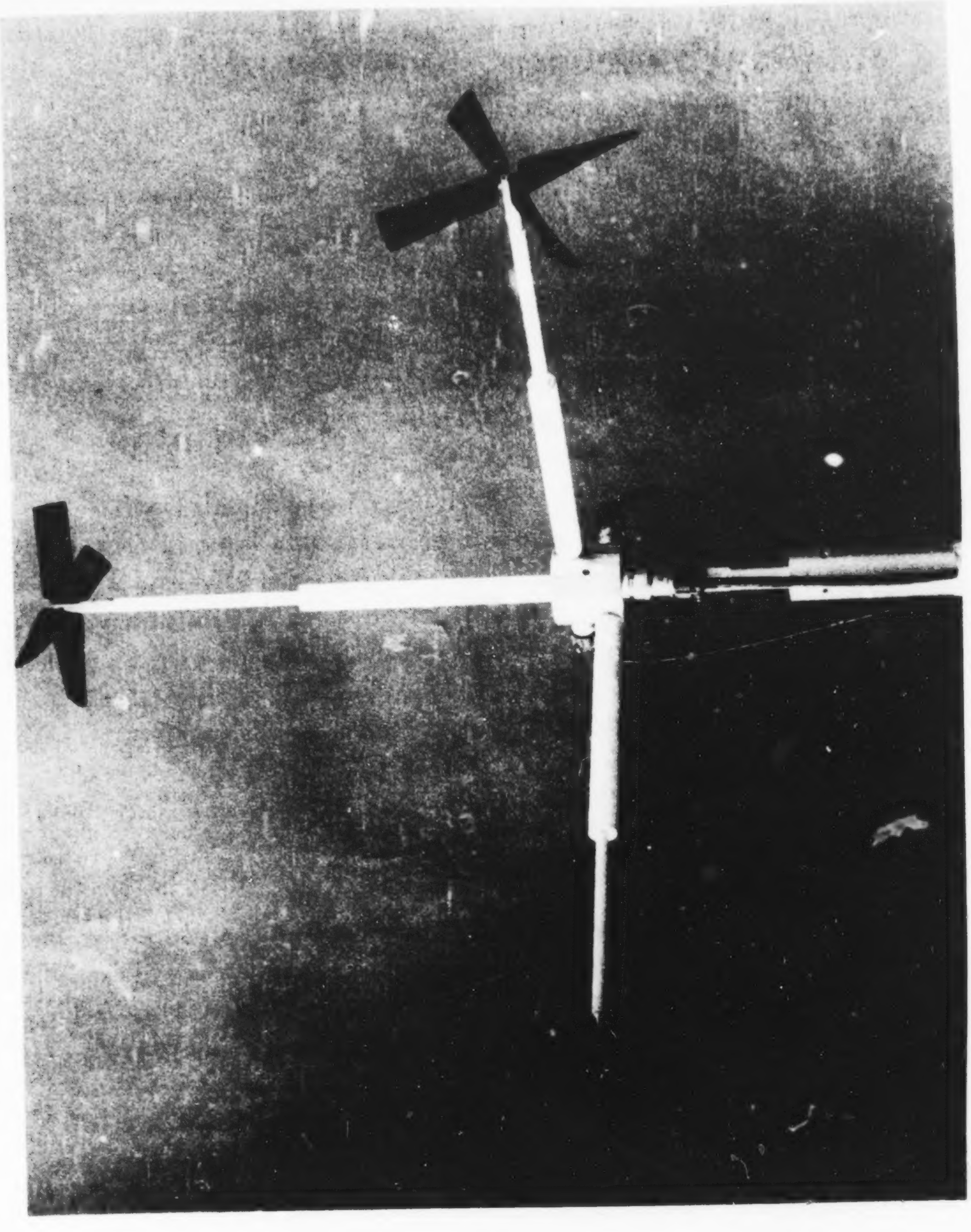


Figure XXIII-3: UVW Anemometer (Courtesy Climet Instruments Co.)

generators is the relatively high starting or threshold speeds. The brush and bearing friction combine to produce a lower limit to the threshold speed of about 1 mph (.5 m/s) on the most sensitive systems. The brushes on these generators usually need servicing only about once a year under continuous use. On some of the more sensitive sensors the unit is sealed and it is recommended that the unit be sent to the factory for servicing or replaced completely.

● A.C. Generator

In an attempt to lower the threshold speed by eliminating brush friction, some manufacturers are using A.C. generators instead of D.C. generators. A.C. generators reduce the friction considerably and eliminate brush and commutator maintenance. A.C. generators are available with either two, four, six, or eight-pole permanent magnet rotors. The larger the number of poles, the more pulses are available per shaft revolution, producing a smoother record.

The largest disadvantage of the A.C. generator is associated with the number of pulses per shaft revolution. These pulses must be rectified by a modifying transducer (rectifier) in order to have a suitable energy form for recording. Low wind speeds generate a low frequency of A.C. pulses and normal rectifiers do not function properly with a low frequency input. Thus, spurious oscillations may be produced at low wind speeds. Therefore, to obtain wind speeds below about 2 m/sec (4 mph) some sort of electronic correction is needed. This disadvantage defeats the purpose of reducing the friction and has therefore resulted in a minimal use of this type of transducer.

● Interrupted Light Beam

Further reduction in friction with accompanying lower threshold speed and quicker response can be accomplished with the use of an interrupted light beam (light chopper) transducer. This transducer employs either a slotted shaft, a slotted disc (Figure XXIII-4), a light source and a photocell, or photo-diode. The cup or propeller rotates the slotted shaft or disc and a pulse is created each time a slot allows light from the source on one side of the shaft or disc to fall on the photocell on the other side of the shaft or disc. The larger the number of slots in the shaft or disc, the smoother will be the output, especially at low wind speeds. The output from the transducer is handled in the same manner as the output from the A.C. generator. The large number of slots (about 100) prevent spurious oscillations in the output at low wind speeds.

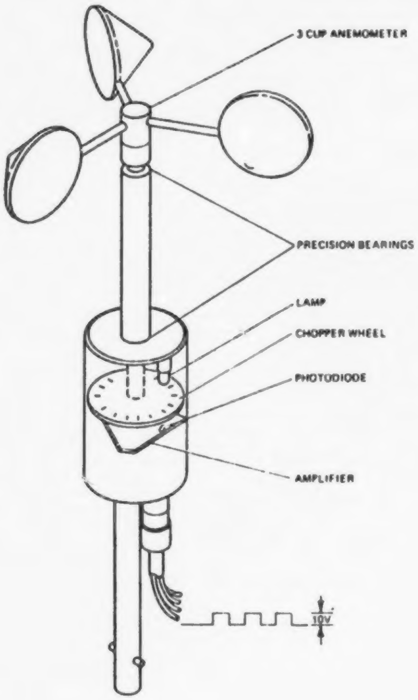


Figure XXIII-4
(Courtesy Climet Instruments Co.)

- Mechanical - contact type

All of the measuring transducers mentioned so far produce an analog signal. There are circumstances where the desired output might be total miles of wind passage instead of a time plot of wind speed. Under these circumstances, a mechanical-contact transducer is used. In this type of transducer, the anemometer shaft is connected through one or more gears to a cam or similar device that opens or closes a contact after the passage of a pre-determined amount of air. This contact closure can operate a readout device such as an event marker pen on a recorder. Recorders can be furnished with circuitry to provide a pen actuation for each 10, 100, or 1000 contact closures in the transducer. If the average wind speed is desired instead of length of wind passage, the number of contact closures are determined for a given time increment and, knowing the miles or meters of wind passage for each contact closure, the average wind speed over the given time increment is easily determined.

Wind Direction Measuring Instruments

- Flat Plate Vane

Typical flat plate vanes are shown in Figure XXIII-5. The term flat plate refers to the tail shape which is simply a flat plate. The flat plate can take on a number of different shapes and be made out of a number of different materials. As with wind speed sensors, the material used in constructing the wind vane will generally determine the proper use of the vane. Vanes made out of heavy gauge metal or plastic should be used only for obtaining average wind direction. The large mass creates a high moment of inertia which will give, under certain conditions, a much higher indication of wind fluctuations than actually exists. The lightweight sensitive vanes have tails made out of thin gauge aluminum or plastic or molded expanded polystyrene. The counterweightss are also close to the center of rotation. This design creates a highly sensitive vane that can be suitably used for turbulence or other fine analyses of the wind trace.

- Splayed Vane

In this type of vane, two flat plates are joined at a small angle (usually about 15^{o}) at one end of the horizontal shaft. This design came about through experimentation that showed that the splayed vane followed small changes in wind direction better than the flat plate. However, the increased mass incurred by two flat plates makes this type of vane unsuitable for anything but the measurement of average wind direction. The splayed vane has, mainly because of its durability and reliability, found widespread use in its role as the main wind direction sensor for the National Weather Service. Therefore, it should be noted that wind direction data

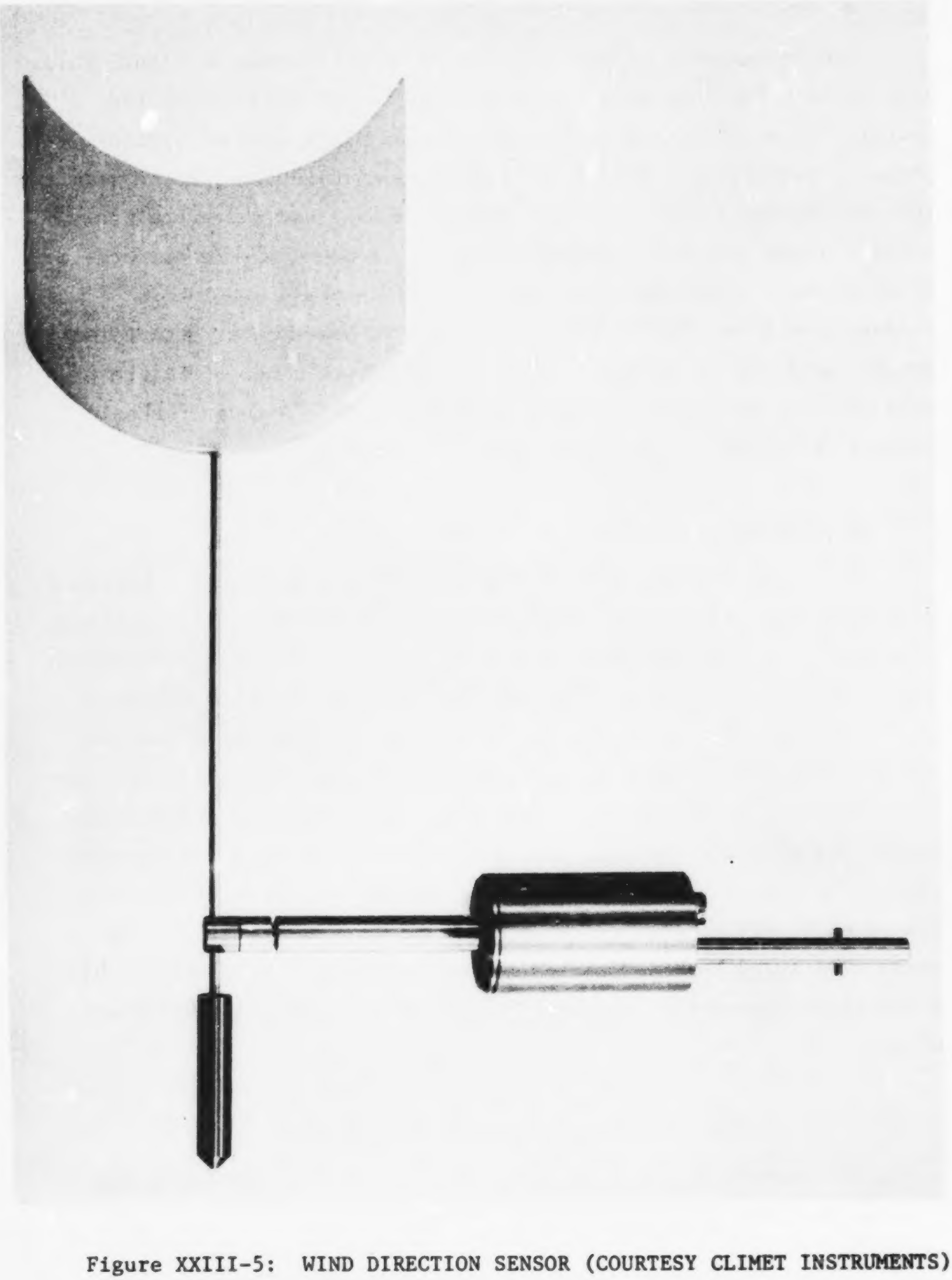


Figure XXIII-5: WIND DIRECTION SENSOR (COURTESY CLIMET INSTRUMENTS)

obtained from a National Weather Service should be used only as an indication of average wind direction.

- Aerodynamic Shaped Vane

The aerodynamic shaped vane has an airfoil cross section. This type of vane has been shown to produce up to 15% more torque for certain ranges of attack angles than a flat plate vane of similar physical dimensions. This type of design, as with the splayed vane, incorporates more mass than the flat plate vane and therefore produces a higher moment of inertia, yielding a poor dynamic performance. An aerodynamic wind vane that has found wide-spread use in air pollution studies the "Aerovane". It should be remembered that its dynamic performance is inferior to the sensitive vanes of Figure XXIII-5, and the use of the data gathered by the "Aerovane" should reflect this fact.

- Bi-directional Vanes (Bivanes)

This type of instrument is designed to rotate around a vertical axis to measure the azimuth angle of the wind, as does a conventional wind vane. It also can move in the vertical to measure the elevation angle of the wind. Because the vertical motions of the atmosphere are frequently of a different character than the horizontal motions (anisotropic turbulence), measurement of both the horizontal and vertical motions are desirable. This is particularly true under stable conditions when the vertical motion is almost absent, but horizontal changes in wind direction may be appreciable. Micropotentiometers are usually used to produce an analog record of both angles. The total wind speed can be measured by replacing the counterweight with a propeller anemometer. Figure XXIII-6 shows a typical anemometer bivane.

Wind Direction Measuring Transducers

The measurement of wind direction consists of converting the angular position of the wind vane to an energy form that can be transmitted easily. Wind direction systems usually employ one of

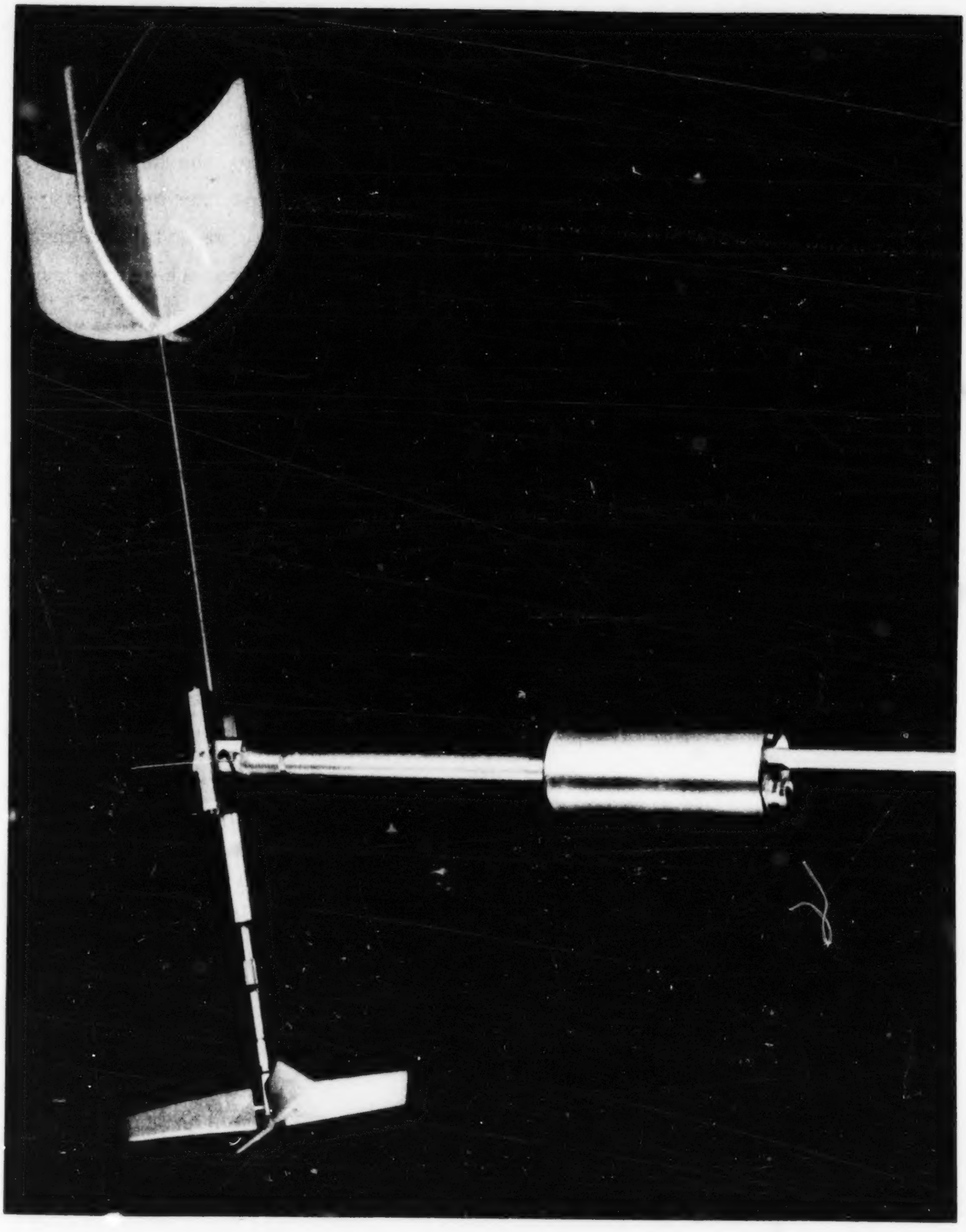


Figure XXIII-6: AXIOMETER WIND TRANSMITTER - BIVANE
(COURTESY CLIMET INSTRUMENTS)

three types of measuring transducers: a potentiometer system, a synchro-motor system or a commutator system.

- Potentiometer System

The most common and inexpensive way of converting the angular position of the vane to an electrical signal is through the use of a potentiometer system. In this system the shaft of the vane is attached to the wiper arm of the potentiometer. The swinging vane therefore produces a continuously varying voltage that can be recorded on a recording voltmeter or dial indicator. With proper calibration, the recorded voltage gives a direct reading of the angular position of the vane.

The biggest drawback to this system is the unavoidable discontinuity in the potentiometer. If the wind direction is oscillating about a direction corresponding to this gap (usually north), the voltage output will oscillate between the maximum and minimum value producing what is commonly called "chart painting." With the recorder pen swinging from one end of the chart to the other, the record produced is, at best, very confusing. There are some types of recorder pen movements available that circumvent this problem. Double contact potentiometers with dual pen recorders produce a trace along each edge of the chart when the wind direction corresponds to the gap. Figure XXIII-6 illustrates a chart record of this type. In newer recorders, there is available electronic circuitry and a 540^{o} chart that can keep the pen trace in the central portion of the chart. Figure XXIII-7 illustrates a chart record of this type.

Wire potentiometers present a problem of excessive wear produced as the contact moves along the wires. The life expectancy of wire-wound potentiometers is only about a year under conditions of continuous operation. Recent advances in this area have produced a conductive plastic potentiometer. The life expectancy of these potentiometers is about 50×10^{6} oscillations, or three to five years, under continuous operation. The linearity of these devices is about .5%.

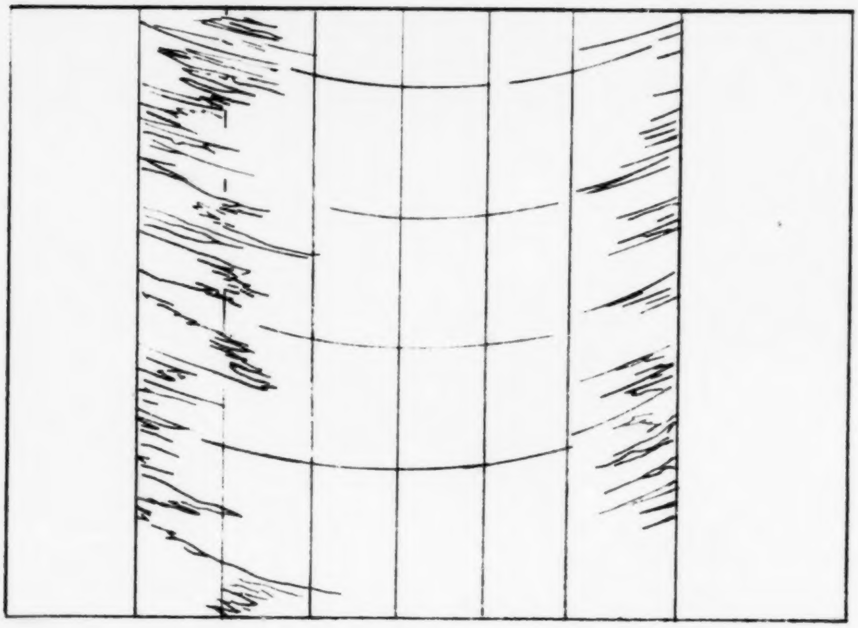


Figure XXIII-7: Dual Pen Recorder Chart

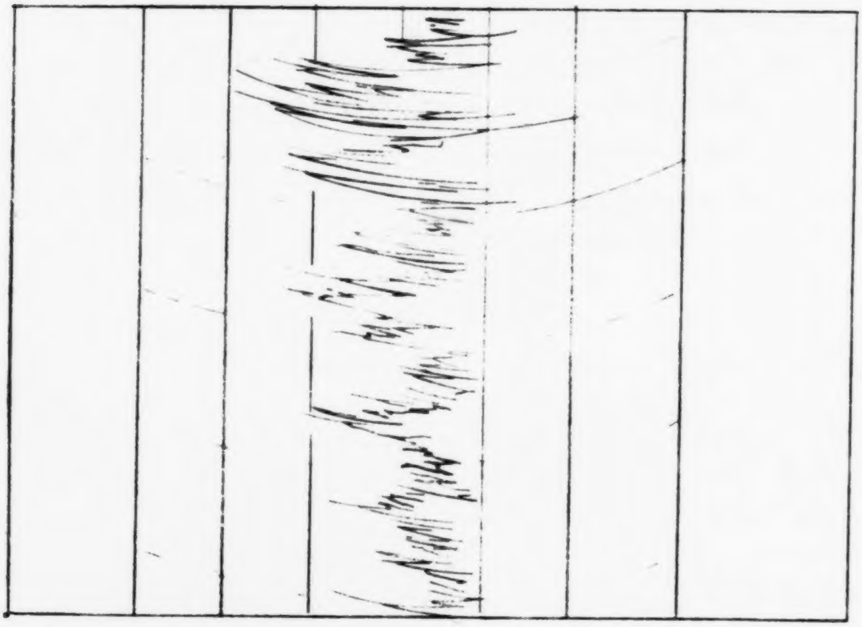


Figure XXIII-8: 540° Recorder Chart

The use of micro-potentiometers produces the lowest moment of inertia of any of the direction transducers available today. This fact has led to their widespread use in the sensitive wind vanes that are noted for their good dynamic performance.

- Synchro-motor Systems

Commonly known as "Autosyn", "Selsyn" or "Synchrotie" systems, this transducer system consists of two synchronous motors wired so that any movement by the shaft of the transmitter will be duplicated by the shaft of the receiver motor, usually to an accuracy of about 2°, provided the lead resistance is kept to a maximum of 20 ohms. The vane shaft is coupled to the shaft of the transmitter motor and the shaft of the receiver motor is coupled to a recorder pen or some other read-out indicator. Therefore, any vane movement is duplicated by a movement of the dial needle, recorder pen, etc., and with proper calibration and alignment, a direct indication of wind direction is obtained. There is no discontinuity in the movement as with the potentiometer. This transducer system is usually coupled with a 540° chart recorder system or a dial indicator to produce an analog trace of wind direction. The system also lends itself readily to a dial indicator display. The only disadvantage of this transducer system is the relatively large moment of inertia of the motor assembly. This produces a poorer dynamic performance than the micro-potentiometer system and limits their use to the more rugged vane types such as the "Aerovane."

- Commutator System

The wind direction transducers discussed so far produce an analog signal that can be converted to an analog chart trace. The commutator transducer system produces contact closures which can be used to activate lights, event marker pens, etc. In this system, the vane shaft is coupled to a unit that has two brush-type contacts spaced 22½ degrees apart.

These brushes make contact with one or two of the eight conducting sectors that are spaced 45° apart and correspond to 45° of wind direction. When both brushes contact the same sector, the direction indicated is one of the eight compass points, eg., N, NE, E. If the brushes are contacting two of the sectors, the indicated direction corresponds to an intermediate direction, such as NNE, ENE, ESE, etc. Therefore, direction indication to 16 points can be obtained with this system. The friction inherent in the commutator transducer as well as the crude method of display make this transducer most applicable to operations involving only the acquisition of average wind direction.

Airborne Sensors

Fixed location wind velocity sensors measure the wind at a fixed height as it varies with time. Most airborne sensors are used to average wind velocity through a given depth of the atmosphere at a particular time.

- Pilot Balloon (pibal)

This method of measuring wind velocity uses a gas-filled free balloon which is tracked visually through a theodolite. The theodolite is an optical system used to measure the azimuth and elevation of the balloon. When only one theodolite is used, the balloon is inflated to have a given amount of free lift. The elevation and azimuth angles are used with the assumed ascent rate to compute wind directions and speeds aloft. By using two theodolites to track the pibal, the ascent rate of the balloon is not assumed, but calculated from the elevation and azimuth angles of the two theodolite observations taken simultaneously. The two theodolites are set a known distance apart (the baseline). Two types of pilot balloons frequently used reach 3000 ft. within five minutes and eight minutes, respectively, after release. If detailed structure of winds with height is to be determined, readings of azimuth and elevation angle must be read every 15 or 30 seconds.

- Rawinsonde

This method of measuring wind velocity aloft also uses a gas-filled free balloon, but is is tracked either by radio direction finding apparatus, or by radar. The former method is the most frequently used in the U.S. The radio transmitter carried by the free balloon is usually used to transmit pressure, temperature and humidity information to the ground (radiosonde). The radio direction finding equipment determines the elevation angles and azimuth angles of the transmitter. The height is determined by evaluation of the temperature pressure sounding. Using radar the slant range is available for determining height. Soundings taken with this type of equipment are made on a routine basis for supporting forecasting and aviation activities. The ascension rate of these balloons is on the order of 1000 feet/minute, so they do not yield as detailed information on winds in the lowest part of the atmosphere as is desired for many air pollution meteorological purposes.

- Rocket Smoke Plumes

A system using a cold propellant, recoverable rocket to emit a vertical smoke trail to an altitude of 1200 feet has been developed by Gill, Bierly, and Kerawalla. This smoke trail is photographed simultaneously at short time intervals by two cameras 2000 feet from the launch site and at right angles to each other. The difference in position of the smoke trail from two successive photographs is a measure of one component (north-south for example) of the wind and can be determined at any number of heights from gound level to 1200 feet. Another system has been reported by Cooke (2).

- Constant Level Balloons

Unlike the previous airborne sensors for wind velocity which obtain average measurements through a vertical layer, constant level balloons are used to determine the trajectory or path of an air parcel during a given time interval. In order to maintain a constant altitude -- more accurately to fly along a constant air density surface -- the balloon must maintain a constant volume. A tetrahedron shaped balloon (tetroon) of mylar has been used for this purpose, having been tracked visually and by radar (1).

C. TEMPERATURE LAPSE RATE

The vertical structure of temperature gives an indication of the stability and turbulence of the atmosphere.

Temperature Difference Measurements

One method of estimating the vertical structure of temperature is by measuring the difference in temperature between sensors mounted at different heights. This, of course, gives an average condition between any two particular sensors.

- Heights of Sensors

Because of the pronounced influence of the earth's surface on the atmosphere's temperature, it may be desirable to measure temperature difference at closer intervals near the ground than at higher levels. For example, a 300 foot tower might have sensors at 5 feet 25 feet, 50 feet, 100 feet, 200 feet, and 300 feet. The height differences at the upper levels should be about equal so that the height of inversions may be determined. Radio and television towers are good supports for temperature difference sensors (as well as wind sensors) and stations usually are willing to allow sensors to be mounted upon their towers. Of course, sensors must be kept below the level of the transmitting antenna.

- Sensors

Resistance thermometers of copper or nickel may be used for temperature difference systems. Thermocouples of copper-constantan or iron-constantan also make reliable sensors. Resistance thermometers and thermocouples do not have to be frequently calibrated and may be expected to provide good service for 10 to 20 years if properly installed. Thermistors are not generally recommended because they may be quite variable from unit to unit and they may require recalibration more frequently than the other two types of sensors. Rapid response is usually not desired in measuring temperature differences. Rather, averages on the order of 5 minutes are desired. If the sensors are 1/2 to 5/8 inch in diameter, they will respond slowly enough to give an average temperature.

- Shielding and Ventilating

Guidelines for the exposure of temperature sensors can be best found in references (3), (4), (7), and (10).

- Recorders

Generally multiple point (10 or 20 points) recorders are used for recording temperature differences. Thus, one recorder may be used for the entire system. The recorder is connected to one sensor for about 30 seconds, prints and then switches to another level. If a six minute cycle is used (print for each level every 6 minutes) there will be 10 readings every hour and an hourly average may easily be obtained by adding the 10 readings and shifting the decimal point one place. The sensors are usually wired so that the temperature differences are obtained directly rather than determining the temperature at each level.

Balloon-borne Sensors

Temperature sensors may be lifted by either free or captive balloons. By this method, temperature, not temperature difference, is measured.

- Radiosonde

The method of radiosonde (radio-soundings) observations is used routinely for temperature, pressure and humidity soundings of the upper air. A free balloon carries the sensors and a radio transmitter aloft. Cycling from sensor to sensor is by means of an aneroid barometer and consequently is a function of pressure. Observations are normally made twice daily at 0000 GCT and 1200 GCT at approximately 70 stations in the contiguous U.S. The ascent rate of the balloon is about 1000 ft/minute. Generally only four to six temperature readings are recorded within the lower 3000 feet so the vertical temperature information is not too detailed. It is still of considerable use when more detailed information is not available.

- T-Sonde

This system consists of a temperature sensor and radio transmitter which is carried aloft by a free rising balloon. The main difference between this system and the radiosonde system is that only temperature is measured. Ten to twelve measurements are taken within the lower 3000 feet of the atmosphere, thus giving more detailed structure of temperature with height.

- Tethered Kite Balloon

Using a captive balloon system to make vertical temperature measurements has the advantages of complete recovery of all components of the system, and as detailed a temperature sounding as is desired may be made by control of the level of the sensor. A balloon having fins is much easier to control and gives greater lift in slight winds than a sperical balloon. Most kite balloons can be used in winds less than 15 knots. For air pollution meteorology purposes, the light wind periods are of greatest interest anyway. Because of hazards to aircraft, prior permission from the FAA is required for flights exceeding 500 feet above ground. For additional precautions when using captive balloons, references such as Doebelin (3), Hewson (4), and Middleton and Spilhaus (7) are suggested.

Several methods of relaying the observations to the ground have been used. Using a wiresonde, a resistance thermometer is carried aloft by a kite balloon whose mooring cable contains wires connecting the sensor with a wheatstone bridge on the ground which is used to measure the resistance. Another system uses a modified radiosonde transmitter to measure temperature and humidity. The signal is transmitted to the ground receiver and recording equipment by the same method used in the radiosonde. Cycling from one sensor to another by a battery driven timing device. The temperature sensor is shielded from the sun by the styrofoam plastic and is aspirated by a small motor driven fan. The mooring of this system is by nylon cable marked at intervals to indicate the height of the sensor.

Aircraft Borne Sensors

In some cases, light aircraft or helicopters have been used for obtaining temperature lapse rate measurements. Although there are complete systems commercially available for this method of temperature lapse rate measurement, one can use standard temperature sensors, thermisters, resistance thermometers, etc., and recorders as long as the exposure guidelines are carefully followed (3, 4, 7).

D. THE MEASUREMENT OF SECONDARY METEOROLOGICAL PARAMETERS

Precipitation

Because large particles and water soluble gases may be removed from the atmosphere by falling precipitation, measurements of this element may be needed. Chemical or radioactive analysis of rain water may also be desired.

- Standard Rain Gauge

The standard rain gauge consists of a metal funnel 8 inches in diameter, a measuring tube having 1/10 the cross-sectional area of the funnel, and a large container of 8 inches diameter. Normally precipitation is funneled into the measuring tube. The depth of water in the tube is measured using a dip stick having a special scale (because of the reduction in area). Measurements with this instrument, since they are made manually, give only accumulation since the last measurement.

- Recording Rain Gauge

The recording or weighing bucket rain gauge does give detailed time resolution of occurrence, and amount of precipitation, as a strip chart, with one revolution per day, is used. The gauge consists of a bucket, to hold the precipitation, on a scale, which weighs the precipitation and moves the pen arm, recording the total accumulation on the chart which is calibrated in inches.

- Tipping Bucket Rain Gauge

This precipitation gauge has a bucket with two compartments beneath the collecting funnel. When one side of the bucket collects a given amount (usually 0.01 inch) of precipitation, the bucket tips and empties the precipitation, collecting the next portion in the other side. The bucket movements are recorded on a chart. The number of bucket movements and the time they occur indicate the rainfall amount and rate. This type instrument is not suitable for measuring snow.

- Precipitation Collector

For research purposes, it is desirable to analyze rainfall as to its chemical and radioactive constituents. Since it is desirable to include only precipitation samples, and not material that may fall into the collector during dry periods, a collector which opens only during periods of precipitation has been developed. The sensor has two sets of adjacent wires and a raindrop falling between the wires completes an electrical circuit which removes the cover from a polyethylene container. A small heat source dries the sensor so that the circuit will be broken when precipitation ceases and also so that dew will not form and open the collector.

Humidity

Because of its influence upon certain chemical reactions in the atmosphere and its influence upon visibility, it may be desirable to measure humidity in connection with an air pollution investigation. Also, some air pollutants affect receptors differently with different humidities, so measurement may be of importance in this respect.

- Hygrothermograph

This instrument measures both temperature and humidity, activating pen arms to give a continuous record of each element upon a strip chart. The chart generally can be used for seven days. The humidity sensor generally used is human hair which lengthen as relative humidity increases and shorten with humidity decreases. Temperature measurements are usually made with a bourdon tube, a curved metal tube containing an organic liquid. The system changes curvature with changes in temperature, activating the pen arm.

- Psychrometers

Humidity measurement by a psychrometer involves obtaining a dry bulb temperature and a wet bulb temperature from a matched set of thermometers. One thermometer bulb (wet bulb) is covered with a muslin wick moistened with distilled water. There must be enough air motion to cause cooling of the wet bulb due to evaporation of the water on the wick. A motor driven fan may be used to draw air at a steady rate past the moistened wick while a reading is taken. A sling psychrometer has both thermometers mounted on a frame which is whirled through the air to cause cooling by evaporation. Relative humidity is determined from the dry and wet bulb readings through the use of tables. Continuous measurements of humidity are not obtained using psychrometers.

Radiation

The influence of the sun's radiation upon the turbulence of the atmosphere and upon certain photochemical reactions is sufficient to make measurements of radiation of importance. In addition, radiation may be reduced due to particulate pollution in the atmosphere. Particularly for research purposes, it may be desirable to measure this effect by comparisons between urban and non-urban stations similarly instrumented.

- Total Radiation

The direct radiation from the sun plus the diffuse radiation from the sky may be measured by pyranometers. These instruments are mounted so that the sensor is horizontal and can receive the radiation throughout the hemisphere defined by the horizon.

- Direct Solar Radiation

The direct solar radiation may be measured continuously by using a pyrheliometer mounted upon an equatorial mount to keep it pointed toward the sun. By using filters, different spectral regions of radiation may be determined.

- Net Radiation

The difference between the total incoming (solar plus sky) radiation and the outgoing terrestial radiation may be useful in determining the stability, and hence, the turbulent character, of the lowest portion of the atmosphere.

Visibility

Visibility, in addition to being affected by precipitation, is affected by humidity and air pollution. Frequently, visibility is estimated by human observer. An instrument to measure visibility, called a transmissometer, measures the transmission of light over a fixed baseline, usually on the order of 500 to 750 feet. An intense light source from the projector is focused on a photocell in the detector. The amount of light reaching the photocell over the constant baseline distance is assumed to be proportional to visibility. The transmissometer is restricted to estimating visibility in one direction only.

A transmissometer is also limited in that the light transmission it detects is affected mainly by liquid droplets in the air. It does not detect, to any great efficiency, the particulate matter in the atmosphere. A relatively new instrument, called a nephelometer, has been developed that will indicate visibility as it is affected by particulate matter in the atmosphere.

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